TELESCOPE MAKING 12

ISSN 0190-5570

The magazine *for*, *by*, and *about* telescope makers!

Summer 1981

TELESCOPE MAKING

The magazine *for*, *by* and *about* telescope makers!

Editor: Richard Berry

Associate Editor: Robert E. Cox

Managing Editor: Katherine M. King

TELESCOPE MAKING (ISSN 0190-5570) is published quarterly by AstroMedia Corp., P.O. Box 92788, Milwaukee WI 53202. Copyright © 1981 by AstroMedia Corp., all rights reserved. No part of this issue may be reproduced by any mechanical, photographic or electronic process or otherwise copied for public or private use without written permission of the publisher. The opinions expressed in this magazine are not necessarily those of the publisher or editors. POSTMASTER: When undeliverable, send form 3579 to publisher. Direct all inquiries, complaints, editorial submissions, and other correspondence to: TELESCOPE MAKING, P.O. Box 92788, Milwaukee, WI 53202; telephone (414) 276-2689. Not responsible for unsolicited materials. Names and addresses of authors will be printed unless specifically requested otherwise. Subscription price (U.S.): 1 year $10.00; single issues $2.50; other countries: 1 year $12.00, single issues $3.00. Clubs and dealers: Inquire about bulk rates. Copy Editor: Ross Parker Simons; Typing: Dianne Precourt Cuneo & Mari Wing; Art Assistants: Jane Borth and Mary MacAdam; Advertising: Mary Kuklinski. Printed by Port Publications, Port Washington, WI.

In this issue. . .

2 Editorial
3 Letters
4 Newtonian Aberrations
by David Stoltzmann
14 The Cost of Amateur Telescopes
by Graeme White
20 Riverside 1981
by Richard Berry
30 Grinding Large, Thin Mirrors
by Bob Kestner
36 Constructing a Club Observatory
by Mark Urbaetis
44 Blue Pages Advertising

Cover: Bob Kestner and his 25.5" thin mirror.
See page 30 for the accompanying article.

Editorial

As you read it, you'll find that this issue is a bit biased toward rather long articles with a theoretical bent. But even if math is not your forte, I think you'll find the results are of interest. We are also beginning a very important series by Bob Kestner on the working of big, thin glass mirrors.

The next issue will be different. For several issues, I have set aside relatively short articles about telescope projects and how-to information, and will be putting them together in TM#13. (I have done this before with #5, #7, and #10, so don't be alarmed.) I mention this to calm the nerves of those of you who submitted an article several months ago and may have begun to wonder what's happened.

As you may know, at this year's Riverside, I was awarded the Clifford W. Holmes Award. I feel honored that you feel that I have helped your hobby and contributed to it. But I want to recognize, in turn, contributors to TELESCOPE MAKING — people who have shared their insight, knowlege, and experience with the rest of us. An editor depends entirely on the willingness of other people to do the nitty gritty work. I follow, gleaning scraps of information, offering encouragement to keep you writing, then putting it into shape for the printed page.

With this issue, TM completes three years of publication. It's been a long three years for me — and much has happened. Back at the outset, I wondered if we could find enough material — now I know there will never be any shortage. Please keep the articles and pictures coming. . . .

Richard Berry
Editor

TM Subscriptions & Renewals

☐ $10 for 4 issues ☐ New subscription ☐ New Address
☐ $18 for 8 issues ☐ Renewal

Name _____

Address _____

City _____ State _____ Zip _____

Your subscription will begin with the next issue published. Payment must accompany your order. All back issues available at $2.50 each.

When to renew: see your mailing label.
This will be your last issue.

T 053202BERRR927B0 TM16
RICHARD L BERRY
BOX 92788
MILWAUKEE WI
53202

Telescope Making/Circulation Dept./P.O. Box 92788/Milwaukee, WI 53202

Letters

Glass At Last!

Sir / This letter is in response to the letter in TM#10, "Glass, glass, glass!" For plate glass in the St. Louis area, the following is true:
½" is easy to obtain;
¾" is hard to buy locally, but is available out of state;
1" was not available even if ordered out of state;
however, fine-annealed pyrex #7740 sheet glass up to 1.25" thick turned out to be easy to obtain in the St. Louis area.

In buying a 24" blank for myself, the best price I got was from United Lens. It was $40 cheaper — even including shipping — than what I could get locally. Their address: United Lens Co., Inc., Southbridge, Mass. 01550; phone 617-765-5421. There is a minimum order of $50 with a three to four week waiting period. Enclosed is a price list which I used for my order in December 1980.

Rolled Sheets — Pyrex No. 7740
prices per 12" square

Thickness	Coarse annealed	Fine Annealed
⅜"	$9.35	$15.75
½"	12.65	21.25
⅝"	17.35	28.90
¾"	20.60	34.30
⅞"	24.75	41.25
1⅛"	32.75	54.50
1⅜"	45.00	74.60
1⅝"	60.00	100.75

I hope you are still planning to do an article from Bob Kestner on his methods of figuring large thin mirrors. All of us working with big mirrors will appreciate Bob's advice.

Ollie Deppong
318 S. Forest Ave.
Webster Groves, MO 63119

— Part 1 of Bob's article is in this issue of TM.

More Glass!

Sir / I am responding to your request for the source of glass mirror blanks.

Back in 1979, I was looking for a large mirror blank, and not being able to find one, I called the Corning Glass Works. They referred me to a local company, a distributor, as a supplier for the pyrex blanks. I bought a 20" disk 1¼" thick and made a 20" f/5.6 Dobsonian with it.

Anyway, the supplier I found sells #7740 Pyrex in sheet form. They will cut any size disk you want up to 30 inches in diameter, and up to 1¼" thick. The supplier is:

Cincinnati Gasket Packing and Mfg., Inc.
40 Illinois Avenue
Cincinnati, OH (Reading)
(513) 761-3458

Incidently, they are listed in the yellow pages under "Glass" as a distributor for Corning.

It may also be helpful to know that patio stones come in 18 and 24" diameter sizes and make handy bases for tile tools once the curve has been roughed in. I built up the curve using latex concrete. Be sure to seal before applying the pitch lap — I used spar varnish. To generate the curve, I used a 12.5" blank and a lapping machine with the mirror on the bottom and #45 silicon carbide. I was removing .010" per hour with constant lapping.

By the way, these blanks are plano/plano and polished on both sides, giving a good flat back for the cell. Check the local yellow pages for distributors.

Richard J. Wessling
The Pines Observatory
5429 Overlook Drive
Milford, OH 45150

Condensation Problem

Sir / Last year I built a small observatory for my C-8. Though it has served admirably, there are a couple of problems that your readers may be able to help me with.

First, let me give a little background. This 10' domed observatory is constructed on cement posts, 2 x 8 joists, plywood siding nailed over 2 x 4 walls 4 feet high, with an octagonal perimeter. The dome is of ⅛" exterior masonite, nailed and glued to curved ribs cut from ¾" plywood. The viewing aperture is covered with a lift-off lid, also of ⅛" masonite. All joints were sealed with DAP Black-Tite asphalt base caulking compound and everything was spray painted with two or three coats of exterior white latex house paint.

Now the problem. The winters here in Oregon are very wet, and although there were no leaks initially, the upper half of the dome interior was very wet after a protracted December storm. Condensation was apparently the culprit. Then, the glue holding the dome skin to the ribs began to loosen and run. (I had been wrongly advised at the local lumber yard that Elmer's Professional Carpenter's wood glue is waterproof!) I suppose there is no hope of the glue "resetting" itself when the dome dries thoroughly — or is there?

Recently, two or three spots on the seams of the dome exterior showed the paint "blistering." When punctured, the blisters leaked water. The blisters occurred on the caulk material, and on the inside of the dome those locations were wet.

My questions are as follows:

1) What should I do to eliminate the condensation inside?

2) How much ventilation in the peak of the dome is required?

3) Should the dome interior be painted (and if so, with what type paint)?

4) Should I cover the exterior dome seams with something like a mobile home roofing compound? If so, do I need to remove the latex paint and get down to bare masonite?

These problems notwithstanding, the observatory has been a real asset. Most of my observing centers around astrophotography, so having a place to leave equipment set up and ready to use is a real blessing in the midst of a busy schedule.

Thanks in advance for any help you can render.

Pastor Richard A. Steeg
Route 3, Box 268-B
Gaston, OR 97119

— If any reader can help Pastor Steeg, please also send TM a copy of your letter. Low-cost, lightweight dome "technology" is something we all have an interest in.

Sonotube Wax

Sir / I phoned three weeks ago to ask you how to finish a tube for a Dobsonian Telescope. What I subsequently tried on the piece of "BW" column form (which I bought from

➤ 48

Newtonian Aberrations

by David Stoltzmann

Because Newtonian telescopes are so common, understanding their aberrations is important. "Newtonian Telescopes," in TM#9, gave a concise summary of the aberration equations for the Newtonian telescope. From those equations, a telescope user can independently compute the magnitude of each of the aberrations associated with the Newtonian. The article also described the shape and character of the blurs for each aberration type.

Of course, the resultant image in the Newtonian is a combination of the various aberration types, and this combination ultimately produces the actual blur we either see or photograph through the telescope. Therefore, to understand Newtonian aberrations, we must ask some questions.

- How do the individual aberrations (e.g., coma, astigmatism) combine to form the actual blur spot on the image plane?
- How does this blur spot change in size and shape with focus position?
- How does the size of this blur spot change with Newtonians of different aperture, different f-number, and different points in the field-of-view?
- Can you do anything about the magnitude of the blur spot in a Newtonian — specifically to improve it — by changing the construction of the telescope (e.g., by changing the location of the aperture stop)?

To investigate these questions and others as they arise, let's look just a little deeper into the background of the equations given in TM#9. Here we can find just what the blur spot actually looks like at any point in the field-of-view and at any focus position. And while we are doing this, let's compare what the equations tell us with actual spot diagrams plotted by a computer ray-trace program. This will help us visualize what is happening.

To begin with, let's list the transverse aberration equations at the paraxial image plane for a Newtonian with its aperture stop located at the primary in a fashion similar to those in TM#9:

$$SA3 = \text{Spherical Aberration (blur semi-diameter)} = \frac{-2F\,(1 + CC)}{128\,(f/\#)^3}$$

$$CMA3 = \text{Coma (sagittal blur semi-diameter)} = \frac{SFOV \times F}{16\,(f/\#)^2}$$

$$AST3 = \text{Astigmatism (sagittal)} = \frac{-(SFOV)^2 \times F}{4\,(f/\#)}$$

$$PTZ3 = \text{Petzval Field Curvature} = \frac{(SFOV \times F)^2}{4\,(f/\#) \times P} = -AST3$$

$$DIS3 = \text{Distortion} = 0$$

where,

F = focal length of primary

CC = conic constant of primary
= -(eccentricity)²
= -1 for a parabola; 0 for a sphere

f/# = primary f-number

SFOV = Semi-field-of-view (in radians)
$= \frac{\text{Semi-field-of-view (in degrees)}}{57.3 \text{ degrees/radian}}$

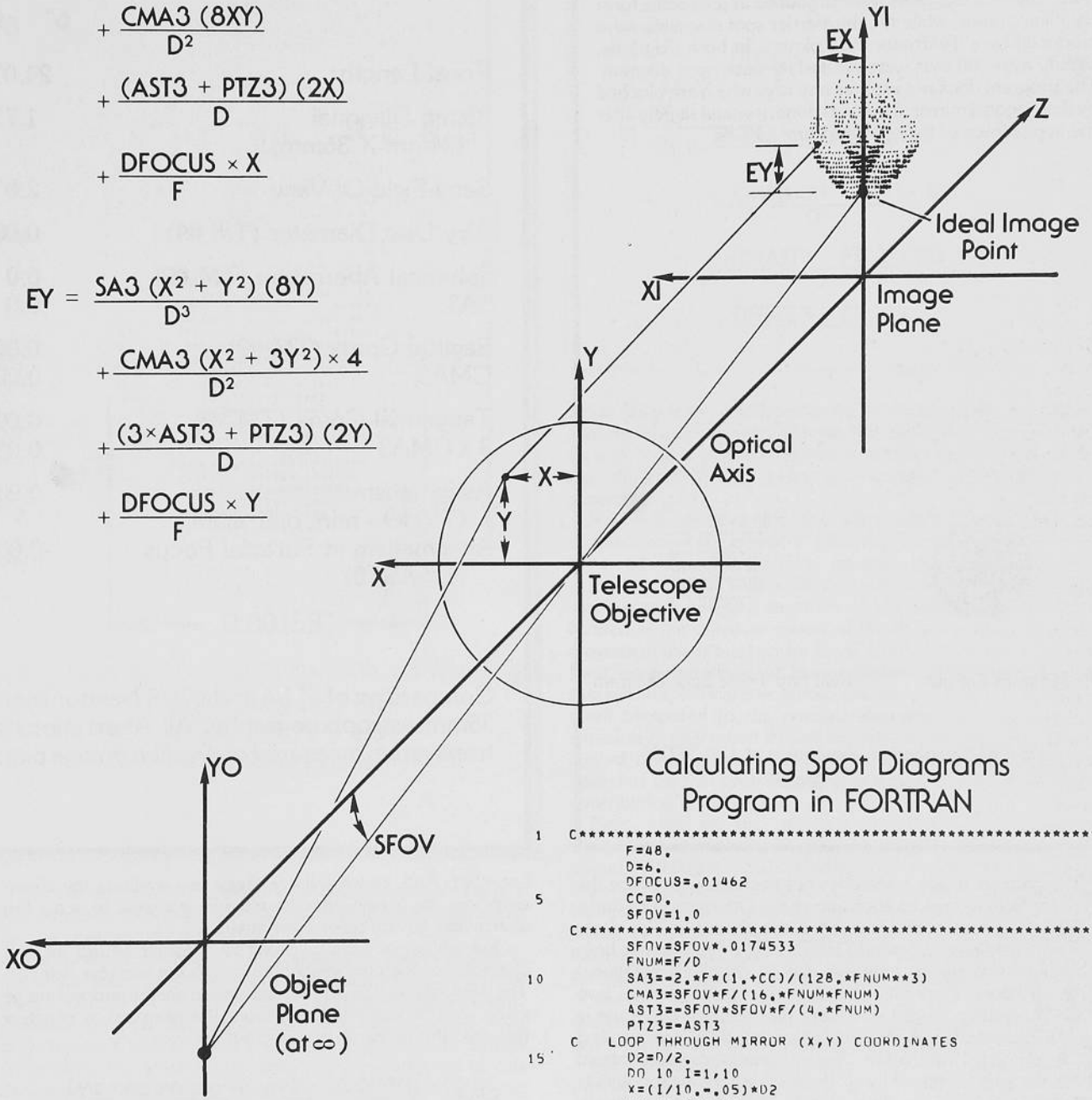
P = Petzval radius
= F (for a Newtonian)

The above aberration equations are called transverse since they are measured in the image plane (for example, on a flat piece of film). Aberrations measured along the optical axis are called longitudinal aberrations, and are equal to the transverse aberration divided by the slope of the marginal ray. Note that the above equations determine the blur sizes for the individual aberrations in the paraxial image plane — one reason they appear somewhat different than the similar equations in TM#9.

Newtonian Third-Order Spot Diagrams

$$EX = \frac{SA3\,(X^2 + Y^2)\,(8X)}{D^3} + \frac{CMA3\,(8XY)}{D^2} + \frac{(AST3 + PTZ3)\,(2X)}{D} + \frac{DFOCUS \times X}{F}$$

$$EY = \frac{SA3\,(X^2 + Y^2)\,(8Y)}{D^3} + \frac{CMA3\,(X^2 + 3Y^2) \times 4}{D^2} + \frac{(3 \times AST3 + PTZ3)\,(2Y)}{D} + \frac{DFOCUS \times Y}{F}$$

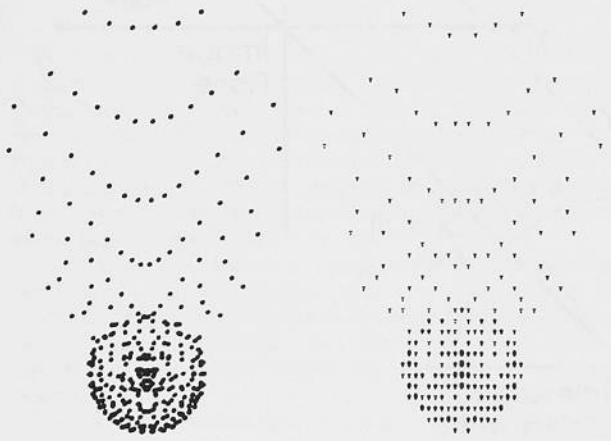


Calculating Spot Diagrams Program in FORTRAN

```
      C*********************************************************
            F=48.
            D=6.
            DFOCUS=.01462
            CC=0.
            SFOV=1.0
      C*********************************************************
            SFOV=SFOV*.0174533
            FNUM=F/D
            SA3=-2.*F*(1.+CC)/(128.*FNUM**3)
            CMA3=SFOV*F/(16.*FNUM*FNUM)
            AST3=-SFOV*SFOV*F/(4.*FNUM)
            PTZ3=-AST3
      C     LOOP THROUGH MIRROR (X,Y) COORDINATES
            D2=D/2.
            DO 10 I=1,10
            X=(I/10.-.05)*D2
            DO 10 J=1,20
            Y=(1.05-J/10.)*D2
            P2=(X*X+Y*Y)/(D2*D2)
            IF(P2.GT.1.0) GO TO 10
            EY = SA3*2.*Y*P2/D + CMA3*4.*(X*X+3.*Y*Y)/(D*D) +
           + (3.*AST3+PTZ3)*2.*Y/D + DFOCUS*Y/F
            EX = SA3*2.*X*P2/D + 8.*CMA3*X*Y/(D*D) +
           + (AST3+PTZ3)*2.*X/D + DFOCUS*X/F
      C     PLOT (EX,EY) COORDINATE
            EX=-EX
      C     PLOT (EX,EY) COORDINATE
      10    CONTINUE
            STOP
            END
```

Third–Order vs. Real Ray Trace

Here a 6" f/8 spherical primary Newtonian has been evaluated. The real ray trace spot diagram for the same system shows the third-order equations are excellent approximations to the trajectories of the real rays. The "real" ray spot diagrams were produced in grey-scale form on a line printer, while the third-order spot diagrams were produced by a Tektronix 4052 plotter. In both diagrams, slightly over 300 rays were plotted for each spot diagram. The program does not remove any rays which are blocked by the diagonal mirror. If this was done, it would slightly alter the appearance of the spot diagram.



Program Output Real Ray Trace Spot Diagram

for a 6" f/8 spherical Newtonian at 1.0° SFOV
focus = +0.01462"

Aberrations and the Spot Diagram

	6" f/4
Focal Length	24.0"
35mm Diagonal (24mm X 36mm)	1.7"
Semi-Field-Of-View	2.0°
Airy Disc Diameter (TM #9)	0.00020"
Spherical Aberration (TM #9)	0.0
SA3	0.0
Sagittal Coma (TM #9)	0.00337"
CMA3	0.00337"
Tangential Coma (TM #9)	0.00982"
3 x CMA3	0.00982"
Astigmatism (TM #9 - min. blur diam.)	0.00366"
Astigmatism at Paraxial Focus (4 x AST3)	-0.00732"

Comparison of 6" f/4 and 6" f/8 Newtonians for 35mm astrophotography. All Aberrations are transverse, measured on the film (image plane).

The paraxial image plane does not necessarily produce the smallest blurs for a given aberration type. Often one finds that a small defocus can improve some of the aberration blur sizes. The semi-field-of-view (called THETA in TM#9) is taken to be in the meridional plane, although the Newtonian's rotational symmetry does not require this to be the case in general. Two other interesting things to note are that the field curvature is equal in magnitude but opposite in sign to the astigmatism, and the distortion (of the chief ray, but not necessarily the centroid of the blur spot) is zero. Finally, these equations are for objects at infinity, and the aperture stop is located at the primary mirror. (We will look at the effect of changing the stop position later.)

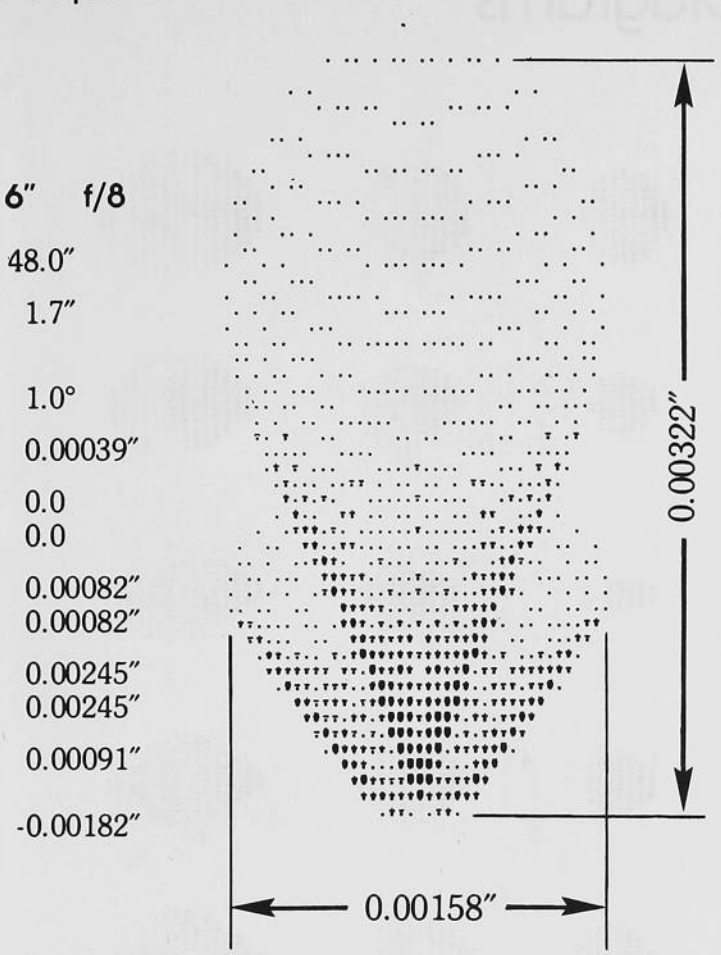
The annotation of the mnemonics with a "3" (SA3, CMA3, etc.) indicates that these are third-order aberration equations, which as given here, are valid for the concave mirror of a Newtonian telescope. These equations can be combined to produce relationships which give the composite blur produced by the telescope. This blur is evaluated at a given point in the field-of-view for a telescope having a particular focal length and f-number. And, as we will see, once you evaluate the above equations for a particular Newtonian, it's easy to scale the aberrations to any other Newtonian.

One additional term we need to consider before we can characterize the composite blur spot is the term for defocus. The defocus term (DELT) as measured from the paraxial image plane, can be positive (away from the primary) or negative (towards the primary), and is given by:

$$\text{DELT} = \frac{(\text{DFOCUS}) \times (\text{ray height on primary})}{F}$$

where DFOCUS is the longitudinal focal shift measured from paraxial focus. Incidently, one can apply this defocus term directly to the equations for the third-order aberrations; for the cases of spherical aberration and astigmatism, positions slightly inside of paraxial focus will result in the minimum blur spot sizes for these two aberrations. These minimum blur sizes are given by the equations in TM #9, and indicate that paraxial focus is not necessarily the position of best focus.

Compared



Spot Diagram For
6" f/8, SFOV = 1.0°
At Paraxial Focus

We are now ready to combine the contributions of each of the individual third-order aberrations to produce a relationship for the resultant aberration blur.

If a telescope were free from aberrations, a point source in the object plane would be reproduced as a single point in the image plane of the telescope. In the presence of aberrations, however, each ray passing through the telescope objective (at coordinates X and Y) actually hits the image plane at a point other than the ideal image point. The coordinates of this aberrated ray in the image plane are given by EX and EY (Error X and Error Y) as measured from the ideal image point.

It is a simple matter to program a computer or pocket calculator to cycle through (X,Y) ray coordinates on the primary mirror, and display print, or plot the resultant (EX,EY) coordinates for the spot diagram.

The coordinates of all the (EX, EY) pairs for each ray passing through the telescope objective (X,Y) define the resultant image blur. The coordinates (EX,EY) resulting from the combination of all the individual aberrations associated with the Newtonian are given by:

$$EX = \frac{SA3\,(X^2 + Y^2)\,(8X)}{D^3} + \frac{CMA3\,(8XY)}{D^2} + \frac{(AST3 + PTZ3)\,(2X)}{D} + \frac{DFOCUS \times X}{F}$$

$$EY = \frac{SA3\,(X^2 + Y^2)\,(8Y)}{D^3} + \frac{CMA3\,(X^2 + 3Y^2) \times 4}{D^2} + \frac{(3 \times AST3 + PTZ3)\,(2Y)}{D} + \frac{DFOCUS \times Y}{F}$$

We thus have expressions for the amount of aberration associated with any particular ray hitting the Newtonian mirror we wish to pick, and if we plot the coordinates of the aberrated ray (EX,EY) a third-order spot diagram can quickly be generated.

Now let us examine the aberrations of two typical Newtonians — the classic 6" f/8 and a 6" f/4 rich-field. For the sake of discussion, let's assume each is used for astrophotography with a 35mm camera at prime focus, and that we wish to know as much as possible about the image formed in the extreme corner of the 35mm frame. The spot diagram of the actual blur for the 6" f/8 illustrates the numbers. First, note that since we have assumed perfect paraboloids, there is no spherical aberration. The size of the Airy disk is very small compared to the residual aberrations, so we have a situation of aberration-limited imagery rather than diffraction-limited imagery at this point in the field-of-view. Coma is apparent in the spot diagram, but also some astigmatism contribution is visible.

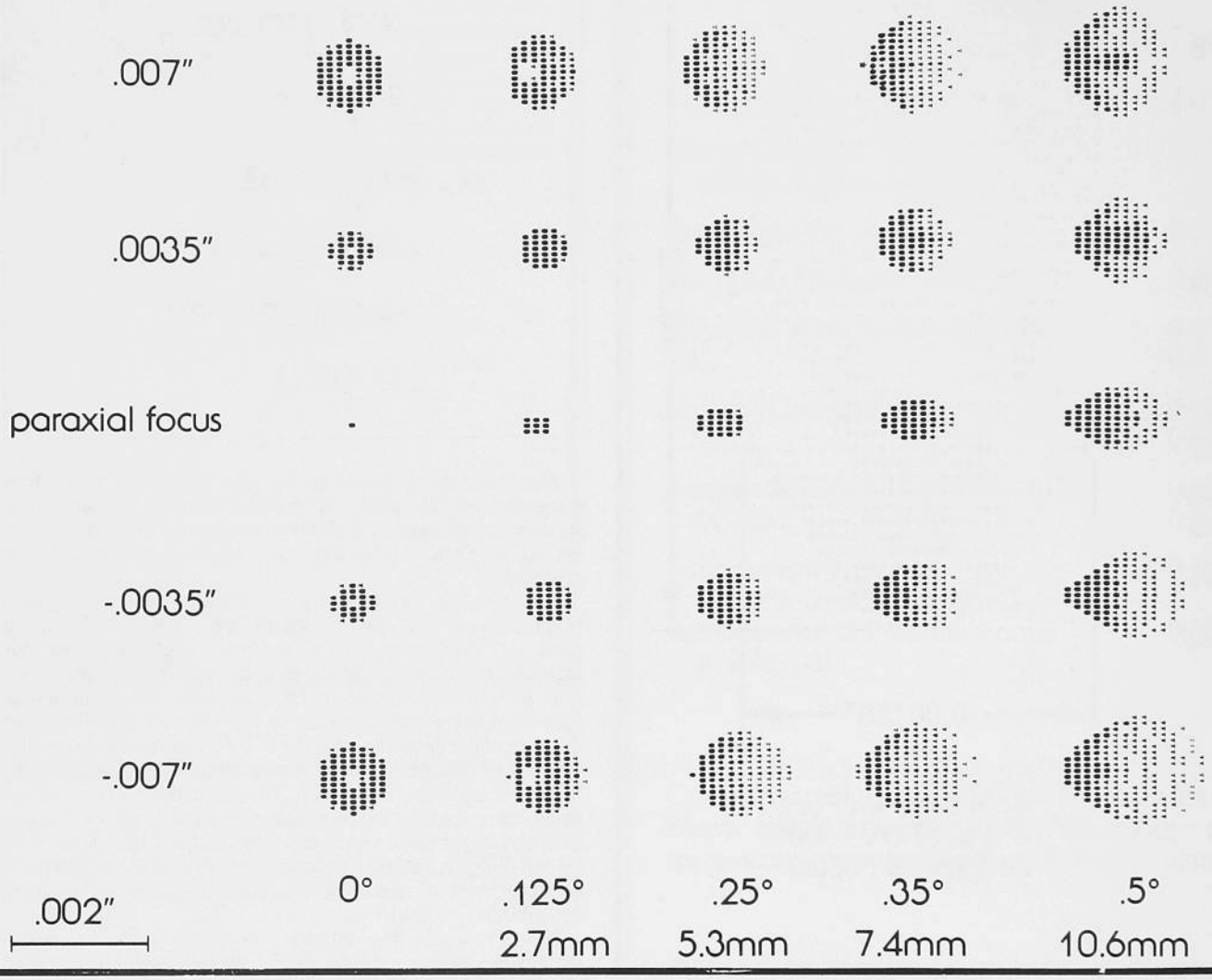
Next, how do the numbers compare with the actual dimensions of the spot diagram? Twice the value for sagittal coma (2 x 0.00082 = 0.00164) should be approximately equal to the width of the blur (0.00158"), which agrees quite well. If the blur consisted of pure coma, then its height (tangential coma) should be equal to three times the sagittal coma (3 x 0.00082 = 0.00245). However, the height of the spot is 0.00322, which is in the ballpark, but less accurate than our estimate for the width of the spot. In fact, the combination of tangential coma and astigmatism lengthens the spot in the tangential direction in precisely the manner shown by the equation for calculating EY.

Cycling through the range of Y values from -3 to +3 inches with X=0 will yield the limiting values for EY. These limiting values span a length equal to 0.00337". Minor differences occur because some rays are obscured by hitting the diagonal mirror and also because the grid of rays traced lies inside the edge of the primary. Thus, the exact rim rays weren't traced. Furthermore, the line printer cannot plot exact ray intersection points — and results in artifacts such as "flat-top" spot diagrams.

Although computing simple third-order values for coma and astigmatism produces a good approximation of the size of the off-axis blurs in a Newtonian, the full picture is told only by the

6" f/8 Newtonian Spot Diagrams

400×



combinations and interactions of the aberrations. In addition, without these equations, we would be at a loss as to how the blur changes with focus position. Extending the equations to produce full spot diagrams covering different field angles and focal positions gives us a powerful tool for understanding the Newtonian.

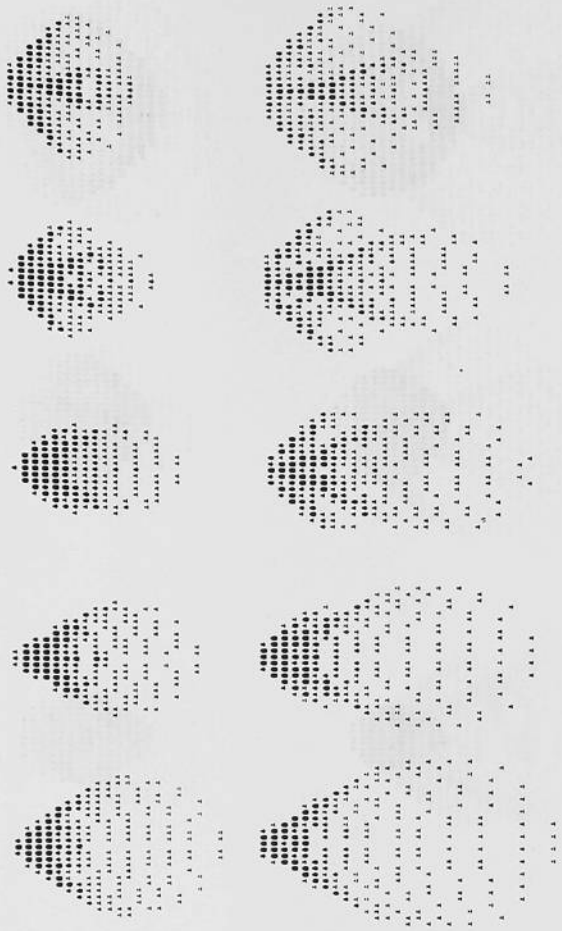
Each array of spot diagrams shows five focus positions relative to paraxial focus for each of seven field points. Scanning over the numbers and examining the spot diagrams, we can draw some conclusions about the telescopes' relative performance. As expected, the blurs for the f/4 telescope are four times larger than those of the f/8. This is because we have kept the same linear field at the image plane in both telescopes, which means the f/4 covers twice the FOV as the f/8.

Although we have chosen to use a 35mm frame format at the image plane, the same relative performance for the f/4 and f/8 would also be seen if the same eyepiece were used on both telescopes. In this case, the two telescopes view the same linear field in the focal plane, and with the shorter focal length of the f/4, this results in a greater FOV and correspondingly lower quality images at the edge of the field. An additional factor, not considered here, is that the eyepiece would be better corrected for an f/8 cone of light than the faster f/4 cone.

It is interesting to study the complex structure of the blurs due to the interaction of the coma and astigmatism as one racks through focus. Four of the five focus positions for the 1.4° field angle show how the blurs appear on the four focal surfaces of the paraboloid: the Petzval surface (+0.0072"), the sagittal focal plane (0.000"), the surface of best focus (-0.0072"), and the tangential focal surface (0.0143"). The complex nature of the blurs makes it difficult to call any focus position the "best."

Incidentally, for both the f/4 and 6" f/8 telescopes, the diagonal mirrors were placed 6" inside focus, and were given 2.75" and 2.25" minor axes for 21% and 14% area obstructions, respectively. These diagonal sizes insure no vignetting on the 35mm film frame.

Since coma and astigmatism interact heavily in the Newtonian systems we have examined, it is worthwhile to determine the regions in which one aberration dominates the other. If we equate the third-order equation for sagittal coma



Newtonians Compared

f/4 vs. f/8

Compared here, to the same scale, are spot diagrams for 6" f/4 and 6" f/8 Newtonians at the same distance off-axis and the same linear scales.

with the equation for the minimum blur diameter for astigmatism,

$$\frac{SFOV}{16(f/\#)^2} = \frac{(SFOV)^2}{2(f/\#)}$$

Then, solving for the SFOV,

$$SFOV = \frac{1\ (radian)}{8(f/\#)}$$

$$= \frac{7^\circ}{f/\#}$$

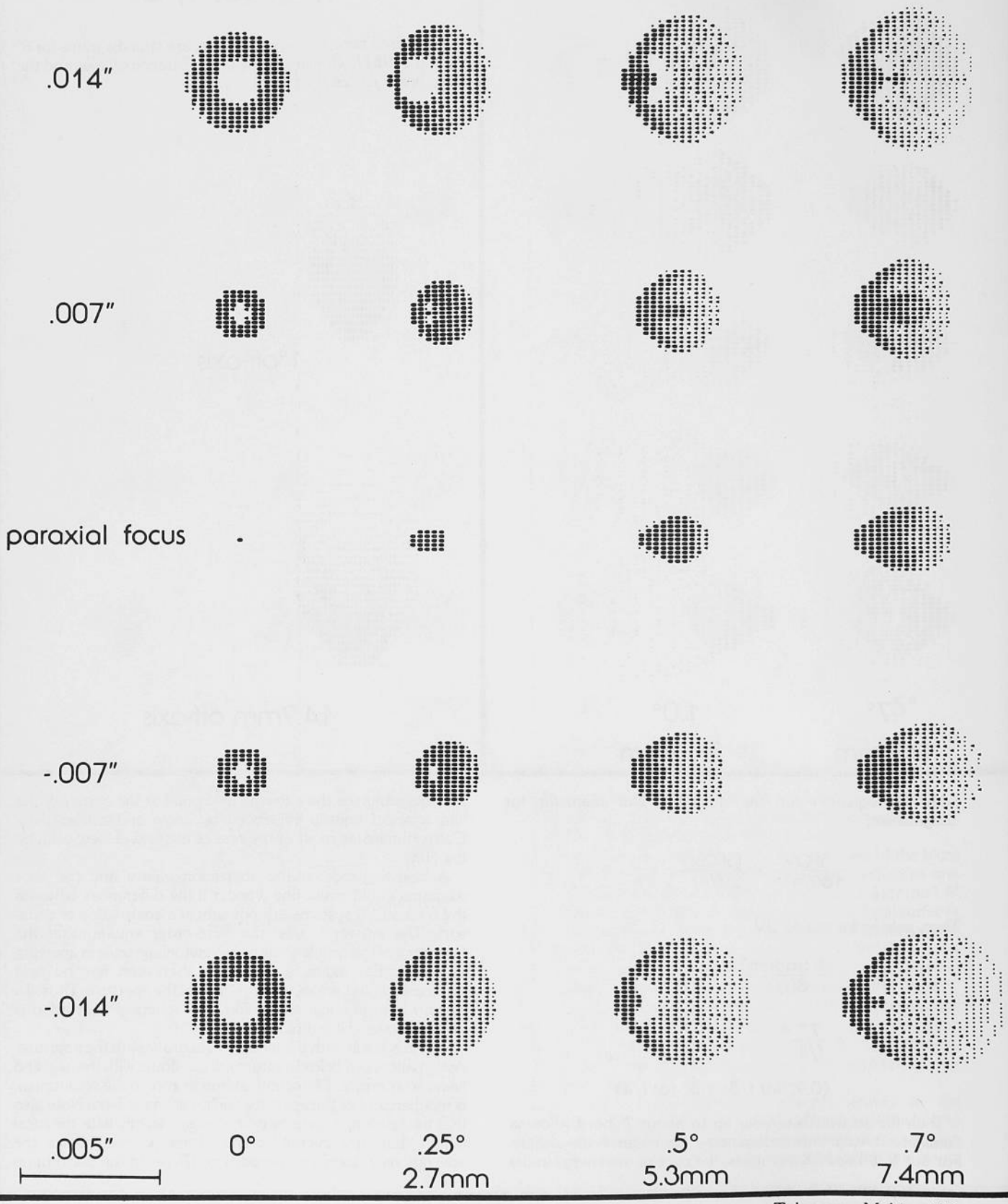
(0.9° for f/8; 1.8° for f/4)

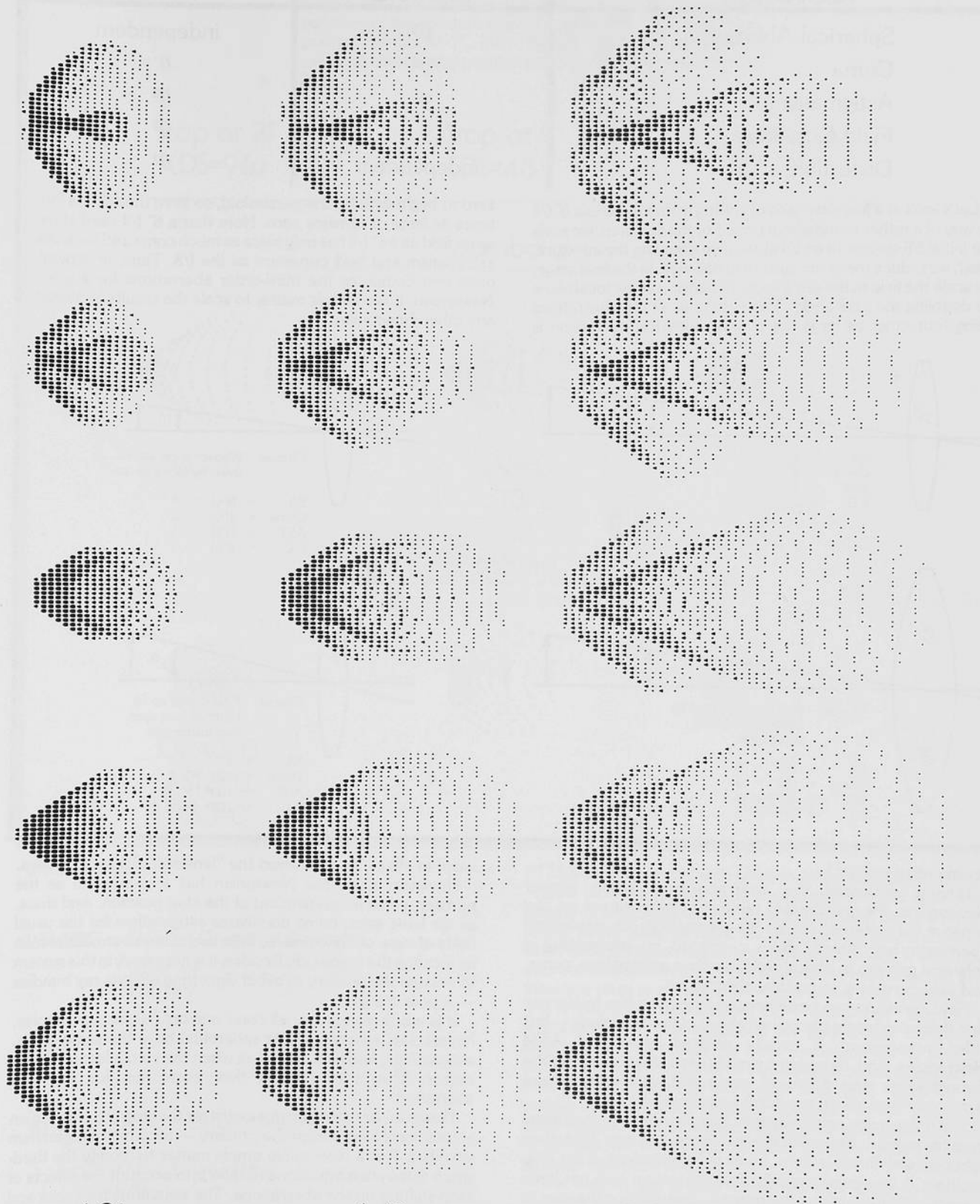
Thus for semi-fields-of-view up to about 7° per f/#, coma dominates. Astigmatism dominates for larger fields-of-view. For our 6" f/4 and f/8 examples, the core of the energy in the spot diagrams for the extreme field point at the corner of the film is about equally influenced by coma and astigmatism. Coma dominates most of the rest of the field-of-view seen by the film.

A casual glance at the aberration values and the spot diagrams could make one wonder if the differences between the f/4 and f/8 systems are not simply a scale value of some sort. The answer is yes: the third-order equations at the beginning of this article show how Newtonians scale in aperture and field. For example, spherical aberration has no field dependence, but scales with the cube of the aperture. Thus, if a system has spherical aberration, the spherical aberration is constant over the entire field-of-view.

Coma is linear with the field, but quadratic with the aperture. Astigmatism and field curvature are quadratic with the field and linear in aperture. Distortion, although zero in the Newtonian, is independent of the aperture and cubic in the field. Note also that the telescope systems do not scale directly with the focal length, but any overall scaling of the system scales the aberrations in the same proportion. (Refer to the diagram on

6" f/4 Newtonian Spot Diagrams
200×

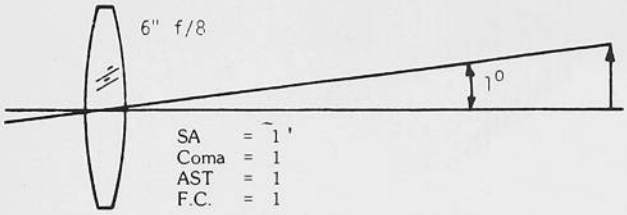



1.0°
10.6mm
1.4°
14.9mm
2.0°
21.2mm

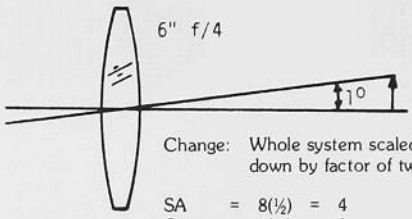
Aberration Scaling

ABERRATION	APERTURE	FIELD
Spherical Aberration	y^3	independent
Coma	y^2	θ
Astigmatism	y	θ^2
Field Curvature	y	θ^2
Distortion	independent	θ^3

Let's look at a few examples of scaling from a 6" f/8 to a 6" f/4 by way of a rather round-about path. For the first step, we scale the initial f/8 system to an f/4 system by doubling the aperture. Next, we reduce the entire system to half-size. In the final stage, we scale the field to the same linear dimension at the focal plane by doubling the field angle. This results in all the aberrations being four times as large. Of course, spherical aberration is zero to begin with for the paraboloid, so even though it is four times as large, it remains zero. Note that a 6" f/4 used at the same field as a 6" f/8 has only twice as much coma and the same astigmatism and field curvature as the f/8. Thus, in general, once one computes the third-order aberrations for a given Newtonian, it is a simple matter to scale the results to almost any other Newtonian.

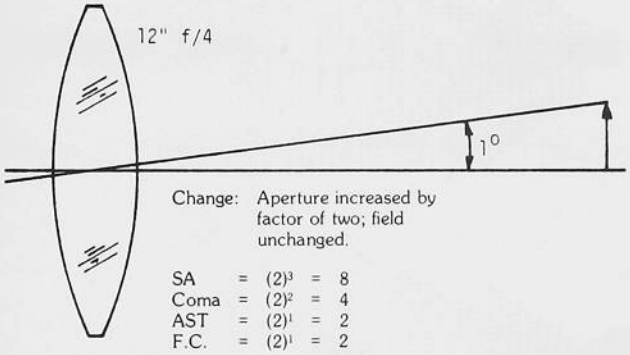


SA = 1'
Coma = 1
AST = 1
F.C. = 1



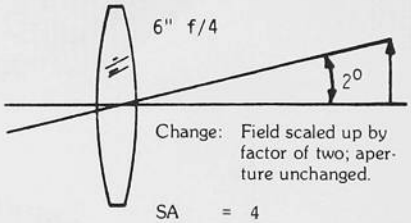
Change: Whole system scaled down by factor of two.

SA = 8(½) = 4
Coma = 4(½) = 2
AST = 2(½) = 1
F.C. = 2(½) = 1



Change: Aperture increased by factor of two; field unchanged.

SA = $(2)^3$ = 8
Coma = $(2)^2$ = 4
AST = $(2)^1$ = 2
F.C. = $(2)^1$ = 2



Change: Field scaled up by factor of two; aperture unchanged.

SA = 4
Coma = 2(2) = 4
AST = $1(2)^2$ = 4
F.C. = $1(2)^2$ = 4

scaling relationships.)

Having evaluated the aberrations in some typical Newtonians, the question still remains whether or not we can improve the system to reduce the aberrations. Since spherical aberration has already been corrected by aspherizing a spherical primary to a paraboloid, we have astigmatism, coma, and field curvature as residual aberrations.

Field curvature can be eliminated by curved film holders or field-flattening lenses placed just ahead of the focal plane — but little improvement is usually realized in normal ATM Newtonians. And, as we have already seen when looking at the through-focus spot diagrams, coma and astigmatism make large contributions on any focal surface we choose.

The only choice remaining is to shift the aperture stop away from the primary. Stop-shift theory tells us, however, that when spherical aberration is zero, coma is independent of the stop position. If, however, the spherical aberration had *not* been corrected by aspherizing the primary, then shifting the stop to the center of curvature would have made coma vanish.

Astigmatism is also zero in the spherical primary case, so we have, in effect, re-discovered the "lensless" Schmidt camera.

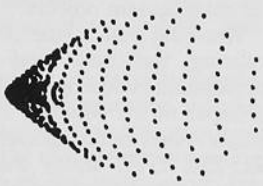
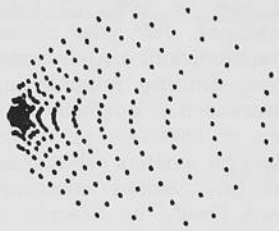
However, since the Newtonian has a paraboloid as the primary, coma is independent of the stop position. And since, as we have seen, coma dominates astigmatism for the usual fields-of-view of Newtonians, little useful improvement results by locating the stop at 2F. Besides, it is necessary in this system to enlarge the primary to avoid vignetting off-axis ray bundles — a poor tradeoff.

It is worth noting that all conic mirrors (ellipses, parabolas, hyperbolas, spheres, oblate spheroids) have the same coma, astigmatism, and field curvature when the stop is located at the mirror. They vary only in their correction for spherical aberration.

However, one position does exist for the stop in a Newtonian — one focal length from the primary — for which astigmatism vanishes. It is a reasonably simple matter to modify the third-order aberration equations to take into account the effects of stop-shifting on the aberrations. The equations for coma and astigmatism are simply multiplied by a stop-shift factor, and spherical aberration remains unchanged and independent of

Stop-Shifted Systems

Shown are spot diagrams at paraxial focus for three different positions of the aperture stop for a spherical and for a parabolic primary at SFOV=1°. Even though coma and astigmatism vanish at certain stop positions, the composite blur is improved little.

Stop at 2F (DS=96)	Stop at F (DS=48)	Stop at Primary (DS=0)
paraboloid		
		
SA3=0	SA3=0 AST3=0	SA3=0 DIS3=0
sphere		
		
CMA3=0 AST3=0 DIS3=0		DIS3=0

the stop position:

$$CMA3(SS) = CMA3 \times (\text{Stop-Shift Factor})$$

$$= \frac{SFOV \times F}{16(f/\#)^2}\left[1 - \frac{DS(1 + CC)}{2F}\right]$$

and:

$$AST3(SS) = AST3 \times (\text{Stop-Shift Factor})$$

$$= \frac{-(SFOV)^2 \times F}{4(f/\#)}\left[(DS/2F)^2 \times (1 + CC) - DS/F + 1\right]$$

where DS is the primary-to-stop distance, positive in sign.

PTZ3 is independent of stop position, and remains equal to to −AST3 (not -AST3(SS), so be careful of this if you alter your program). Distortion will not be zero anymore. But it is not as simple to compute as coma and astigmatism are, and in any case, since distortion has no aperture dependence, it will cause only a constant offset to all the spots in the spot diagram, and therefore does not change the shape of the spot diagram.

It is instructive to substitute DS=F and DS=2F and CC=0 and CC=-1 into the equations for stop-shifted coma and astigmatism. The results we have discussed will be seen to neatly fall out of the stop-shift equations. It is also beneficial to compute through-focus composite blur spot diagrams for various positions of the stop and values of the conic constant. Even though coma and astigmatism vanish at certain positions of the stop, the composite blur of the remaining aberrations is typically improved little.

The bottom line is that the simple Newtonian gives very nearly its best performance when left alone, and you have to make fairly exotic systems before substantially improving its performance. ■

The Cost of Amateur Telescopes

by Graeme White
35 Young St.
Annandale, NSW
Australia, 2006

Perhaps the greatest problem facing a would-be amateur astronomer starting out in this hobby is the purchase of the astronomer's tool of the trade: a telescope. Should it be a refractor — small, tidy, neat and easy to use? Or a reflector? Or maybe a sophisticated catadioptric instrument? Perhaps it would be better to buy a lens or a mirror, place it in a tube and build a mount for it. Then again, a second-hand instrument might be yet another possibility.

What advice does one give a friend who confides that he has "x" dollars for a telescope and wants you to tell him what type would be best to buy?

This article begins by examining the objects that can be observed with amateur telescopes, then goes on to analyze different functions of a telescope — resolution, limiting magnitude, numbers of stars seen — and their costs as a function of telescope size. We develop criteria for amateur telescopes and examine how various telescope types compare. Finally, we describe a small, cost-effective telescope that can be built for about $10.

Before looking at the cost of astronomical telescopes, let's examine what there is to observe. The universe is made up of many billions of bodies which astronomers group into types. Each of these bodies, because of their differing distances from Earth, has different angular size and brightness.

Martin Harwit, in the *Quarterly Journal of the Royal Astronomical Society* (Vol. 16, p. 378, 1975) gives a list of all the types of objects that characterize the universe. Altogether, he lists 45 different types of objects. I have condensed his list into Table 1. Against each type of object I have placed an example of that object, along with the approximate aperture of the telescope needed to see the example. The aperture estimates are based on my own observing experience and I am willing to concede they may be slightly in error. They are, however, accurate enough to draw general conclusions.

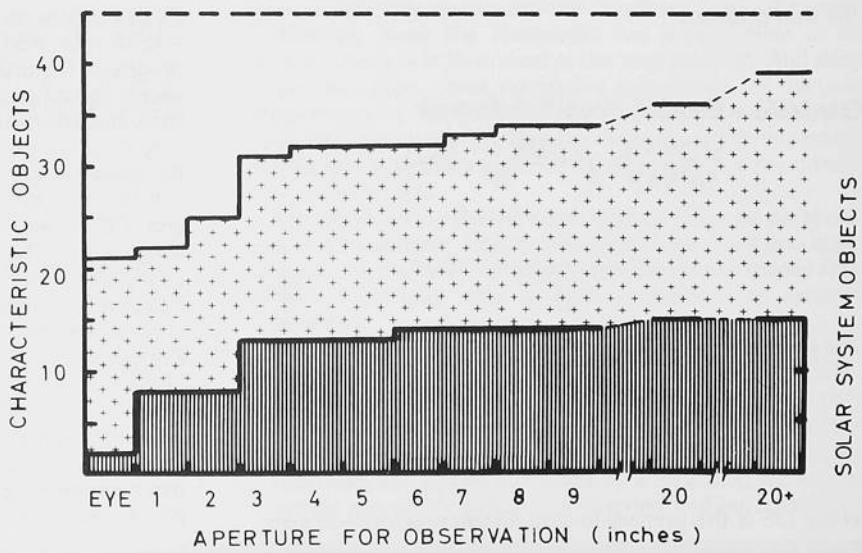
Many of the types of objects do not have bright optical counterparts, e.g., pulsars. Some others, unidentified radio sources, for example, don't have any optical counterparts at all. Indeed, professional astronomers can only examine with optical telescopes 87% of the 45 types of objects that characterize the universe. As amateur telescopes are limited to apertures less than about 20″, examples of only 80% of the object types can be seen even with the best of amateur telescopes.

From the table, we see that one or more examples of each type with an optical counterpart can be observed with the naked eye in 47% of cases. This in itself is an interesting result: it says that little or no optical aid is required to commence an educational study of the universe. All that is required is to have good eyes and to become familiar with the stars — and one will be literally half way there!

Similarly, shown in Table 2 is a list of 15 solar system objects popular among amateur astronomers along with the telescope aperture required for a "good" observation of them. The histograms plotted in Figure 1 show how the aperture must increase to observe examples of the types of objects and the 15 solar system objects.

Knowing that a rule of thumb exists relating the cost and aperture of professional telescopes (M. J. Disney, in a paper in the *Monthly Notices of the Royal Astronomical Society*, Vol. 160, p. 213-232, 1972, states the cost of the instrument is proportional to the cube of the aperture), I set out to discover whether there is a similar relationship for amateur telescopes and optics. For source material, I used the advertisements in *Sky & Telescope* and ASTRONOMY magazines for December 1980. Upon plotting the cost of a completed Newtonian telescope against its aperture on log-log graph paper, I found, sure enough, a relationship similar to that found by Dr. Disney. I repeated the procedure for telescope mirrors, completed refracting

Figure 1. Two histograms showing a) how aperture of a telescope must be increased to observe at least one example of the 45 types of objects that characterize the universe; b) how aperture of a telescope must be increased to observe each of the 15 popular solar system objects (shaded).



telescopes, achromatic objective lenses, and Schmidt-Cassegrain and Maksutov (catadioptric) telescopes. These graphs are given in Figure 2.

Mathematically, the cost of the optical components and the completed telescopes can be expressed as:

$$\text{Price } (\$US_{1980.9}) = CA^n$$

where A is the aperture in inches and both C and n are constants, their value depending the type of item. Their values are:

Item	C	n
Complete Newtonians	4.8	2.37
Telescope mirrors	0.6	2.58
Complete Refractors	33.9	2.65
Achromatic objectives	4.0	2.75
Catadioptric telescopes	46.8	1.56

The spread of the points on the graphs of Figure 2 is an indication of the variation in the quality, accessories, and price structure of the instruments being offered. Many of the instruments are equipped with many extras and sophisticated mountings, while others come with just the bare necessities. It is also worth noting that, on the average, refractors and catadioptrics, although more expensive than their reflector counterparts, are better equipped in terms of mountings and accessories.

Table 3 gives the average cost of telescopes as calculated from equation 1, the average cost of optics, and the cost of the optics as a percentage of the completed telescope.

At these prices, that magnificent lens in the human eye would cost $ .48, which must be the best value yet! Similarly, the new 150" Anglo-Australian telescope at Siding Springs, Australia N.S.W., would cost $690,000 if it were an amateur telescope. In reality, it cost about $25,000,000 (Australian) — but it did come complete with many accessories including a six-story observatory building, onion-shaped dome, two computers, dark rooms, offices, workshops, roads, etc.

It is interesting to note how much of the cost of an amateur telescope is invested in the main optical component. For smaller reflectors the mirrors cost about 16% of the total telescope price. This percentage increases to 23% for the biggest instruments. In Dobsonians, the percentage is higher still — around 60%, — because of the extremely low cost of other Dobsonian materials and the Dobsonian's easy adaptability to very large apertures. The largest refractor — a four-incher — contains a lens worth only 14% of the total cost of the instrument.

The cost of eyepieces for telescopes appears to be quite independent of the eyepiece focal length. The average eyepiece will cost about $23; the cheapest, $16; the most expensive, over $50.

But the real question still is: How much do you see through a telescope for your dollar spent? To answer this question, we must first define why we need a telescope at all. Telescopes have a twofold purpose: 1) to improve the resolving power of the human eye and 2) to allow fainter objects to be observed.

In Figure 3, I have plotted how much it will cost you to obtain a certain resolution (measured in arc-seconds) as calculated by the Dawes Limit (5 arc-sec/inch) for off-the-peg Newtonians (plotted as N), and Refractors (R), and Catadioptrics (C), as well as their main optical components; Mirrors (M), Lenses (L).

This diagram is not the end of the story. We must qualify it as follows:

1) Some telescope manufacturers claim resolution better than Dawes limit for their telescopes.

Figure 2. Cost/aperture relationships for a) completed Newtonian telescopes and their mirrors, b) refracting telescopes and achromatic lenses, and c) catadioptric telescopes.

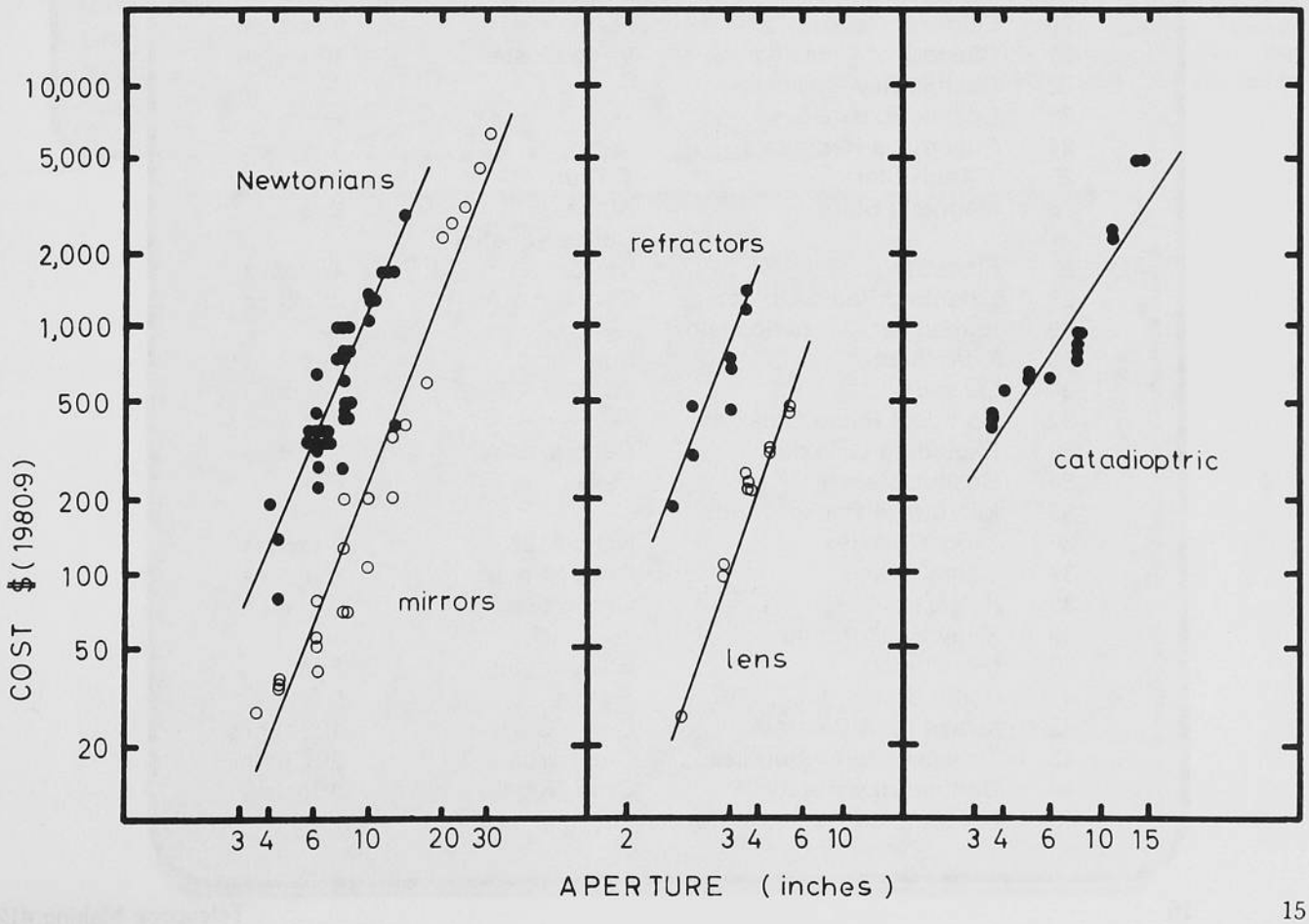


TABLE I

45 Types of Objects that Characterize the Universe

Number	Object Type	Example	Telescope Required
1	Interplanetary particles	Meteors	Eye
2	Planets	Earth	"
3	Asteroids	Eros	1 inch
4	Comets	Comet West	Eye
5	Moons	Moon	"
6	Main Sequence Stars	Sun	"
7	Giants and Supergiants	Betelgeuse	"
8	White Dwarfs	Sirius B	8 inches
9	Pulsating Variables	Mira	Eye
10	Novas	Eta Carinae (in 1843)	"
11	Supernova	Crab (in 1504)	"
12	Multiple Stars	Epsilon Lyrae	"
13	Reflection Nebula	M-42	"
14	Cold Interstellar Gas	Coal Sack	"
15	H II Regions	M-42	"
16	Planetary Nebula	M-57	3 inches
17	Galactic Clusters	Pleiades	Eye
18	Globular Clusters	Omega Centauri	"
19	Spiral Galaxies	M-31	"
20	Elliptical Galaxies	M-87	3 inches
21	Clusters of Galaxies	Virgo cluster	12 inches
22	Cosmic Ray Particles	—	—
23	Cosmic Expansion	—	—
24	Supernova Remnants	M-1	3 inches
25	T Tauri Stars	T Tauri	2 inches
26	Magnetic Stars	Alpha-2 Canes Venatici	Eye
27	Flare Stars	UN Ceti	4 inches
28	Extended Radio Objects	Centaurus A	2 inches
29	Interstellar Magnetic Fields	—	—
30	X-ray Stars	Sun	Eye
31	Quasars	3C 273	7 inches
32	Compact Radio Galaxies	—	20+ inches
33	Exploding Galaxies	Centaurus A	2 inches
34	Cosmic Masers	M-42	Eye
35	Microwave Background	—	—
36	X-ray Galaxies	NGC-5128	3 inches
37	Gamma Rays	Crab Nebula	3 inches
38	Pulsars	Crab Pulsar	20+ inches
39	X-ray Background	—	—
40	I.R. Objects	Eta Carinae	Eye
41	Radio Stars	Sun	"
42	X-rays from Clusters	Coma Cluster	12 inches
43	Transient X-ray Sources	Centaurus X-3	20+ inches
44	Gamma Ray Bursts	Crab Nebula	3 inches
45	Unidentified Radio Sources	—	—

2) There is some debate about the relative resolving power of refractors versus reflectors. Some observers consider the resolving power of a 3″ refractor comparable with that of a 6″ reflector. Three explanations are given for this:

a) The Newtonian reflector image is degraded by diffraction from the flat and the spider. The refractor is not affected in this way and a perfect Airy disk can, therefore, be obtained.

b) Smaller telescopes (i.e., refractors) look through smaller "tubes" of the atmosphere and are less affected by bad atmospheric conditions.

c) Refractors have an enclosed optical path and are less affected by convection currents in the air in the telescope tube.

3) Although our telescopes may be optically perfect, all observers are faced with looking through the Earth's atmosphere. This degrades the image formed by our telescopes. Typically the best resolution we can hope to obtain is on the order of one to one-half arc-second. That implies that there is very little to be gained, in terms of resolution, by owning a telescope of aperture much in excess of 6″ or 8″. To reach this one-arc-second limit, we need a Newtonian telescope costing $220, a refractor costing $2000, or a catadioptric costing $550. For a homemade telescope, the mirror will cost $38 and the lens $340.

The other reason for going to larger telescopes is to observe fainter objects. From *Norton's Star Atlas*, which gives the magnitude of the faintest object visible in a telescope of any given aperture, we extrapolate a little to find the cost of reaching a certain limiting magnitude with a telescope of a certain size (see Figure 4). As before, the M, L, N, R and C notation is used. It is clear that a Newtonian costing $1000 will reach about magnitude 13.9, while a refractor of similar value will reach 13.2, and a $1000 mirror will allow the observer to see stars of magnitude 15.2.

C.W. Allen, in his book *Astrophysical Quantities*, gives the total number of stars that are visible

TABLE 2

Common Objects within the Solar System and Aperture of Telescope Required for Visual Observation

Object	Aperture Required
Sunspots	Eye (plus suitable protection)
Phase of Mercury	3 inches
Phase of Venus	1 inch
Lunar Craters	1 inch
Lunar Mountains	1 inch
Lunar Seas	Eye
Pole of Mars	3 inches
Features of Mars	6 inches
Galilean Moons of Jupiter	1 inch
Great Red Spot of Jupiter	3 inches
Rings of Saturn	1 inch
Cassini division in Saturn rings	3 inches
Uranus	1 inch
Neptune	3 inches
Pluto	12 inches

TABLE 3

	2.4″	3″	4″	6″	8″	10″	12½″	14¼″	16″	18″	20″	30″
Average Cost of Telescopes ($)												
Newtonian telescopes	—	—	128	335	663	1125	1904	2605	—	—	—	—
Refracting telescopes	345	623	1336	—	—	—	—	—	—	—	—	—
Catadioptric telescopes	—	260	407	766	1200	1699	2407	2953	—	—	—	—
Average Cost of Optics ($)												
Mirrors	—	10	21	61	128	228	406	569	767	1039	1364	3883
Lens	44	82	181	52	—	—	—	—	—	—	—	—
Average Cost of Optics as % of Completed Telescopes												
Newtonian telescopes	—	—	16.4	18.2	19.3	20.3	21.3	21.8	—	—	—	—
Refracting telescopes	12.8	13.2	12.5	14.1	—	—	—	—	—	—	—	—

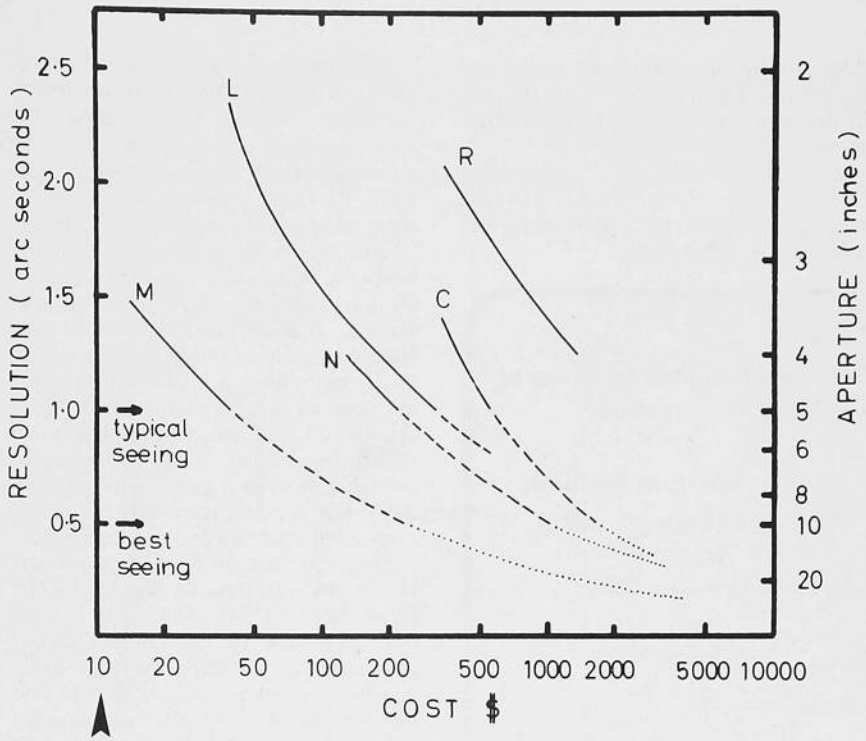


Figure 3. Resolving power in seconds of arc, as calculated from the Dawes Limit, of telescopes for the dollar spent. N stands for Newtonians, R for refractors and C for catadioptrics. The figure also gives resolving power for mirrors, M, and astronomical achromatic objective lenses, L.

in the entire sky to any limiting magnitude. If we define for each telescope the number of "stars per dollar" it gives us, we can plot Figures 5 and 6. These give stars/$ ratios for varying optical diameters.

This parameter is computed from nature's distribution of stars in space, the physical law that governs a telescope's performance, and the price that man places on his instruments. Here, at last, is one way to answer the question that one asks one's self when looking through a new and expensive instrument to decide if it is worth the expense.

In Figures 5 and 6, only the stars/$ ratio for catadioptric telescopes improves with cost. The main point is inescapable — Newtonian reflecting telescopes are about 10 times as effective, in these terms, as other telescope forms.

Finally, Figure 7 shows how a main telescope component, the 6" mirror, has varied in price in the last 25 years. The real cost of 6" mirrors over the years has decreased with increased inflation. A mirror selling for $49.50 in 1960, although still selling for about $50 in 1981, is worth only $12 (1960) due to inflation.

A 1" f/40 non-achromatic astronomical telescope magnifying 20x. The telescope is alt-azimuth mounted on a full height tripod. The total cost of construction was about $10.00

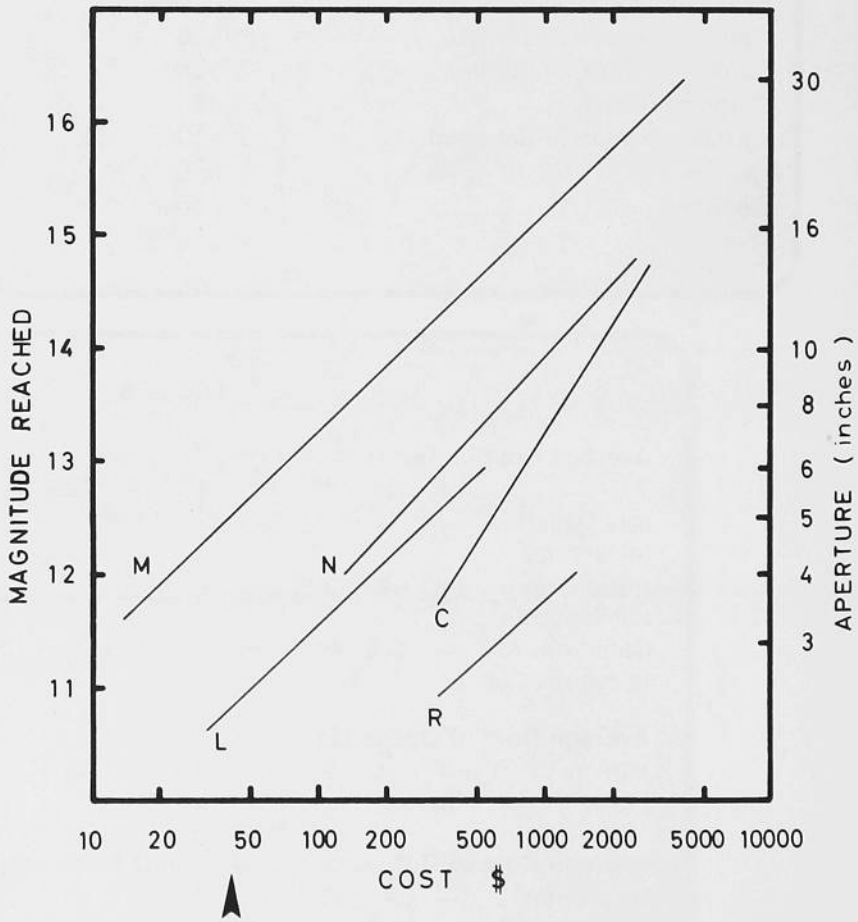


Figure 4. The limiting magnitude visible through telescopes of various sizes and the cost of those telescopes and their optics.

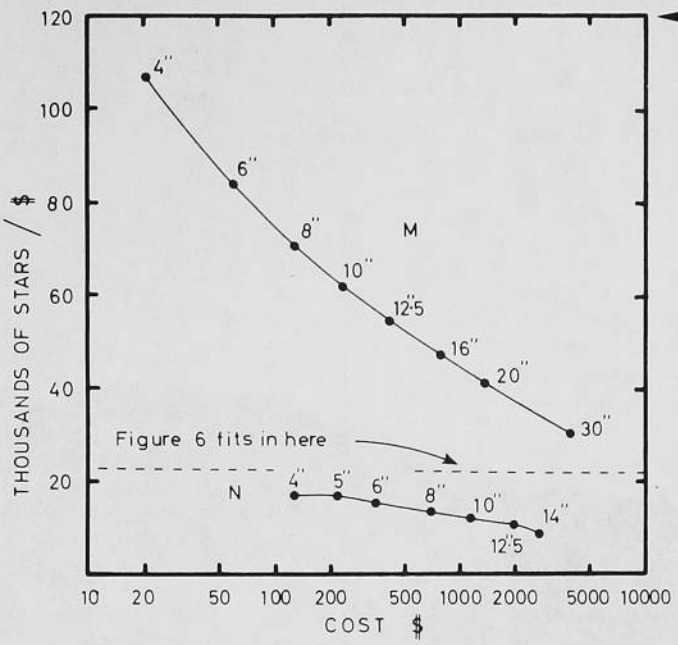


Figure 5. The stars/$ ratio for reflecting Newtonian telescopes and mirrors. N stands for Newtonian telescopes, and M for mirrors.

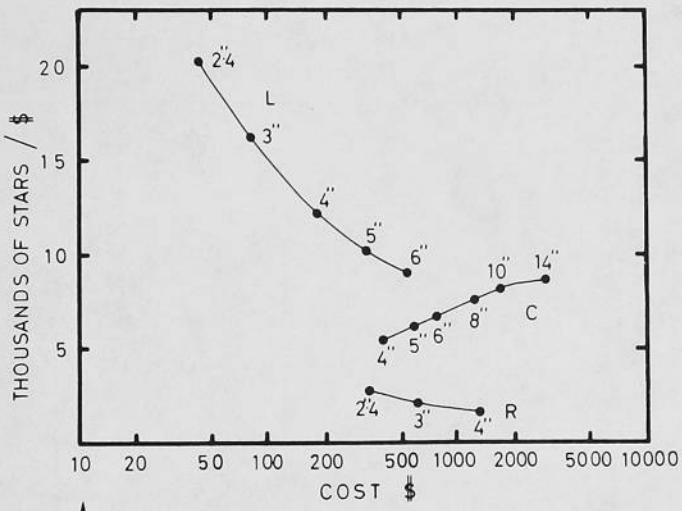
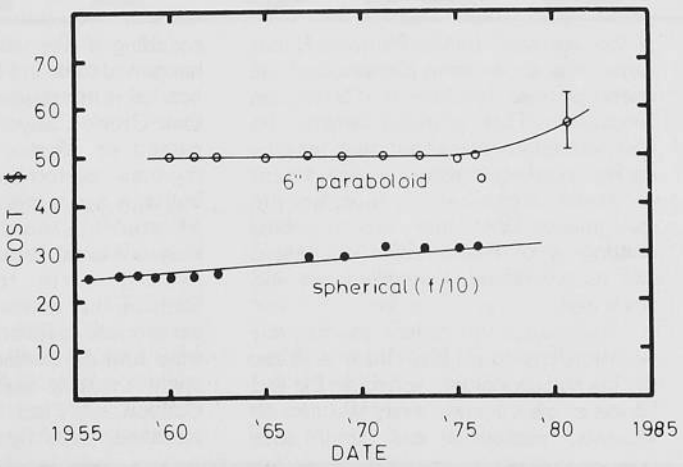


Figure 6. The stars/$ for refracting telescopes, R, achromatic objectives L, and catadioptric telescopes, C.

Figure 7. The dollar cost of 6" telescope mirrors between 1955 and 1981 remained nearly constant.



Given a limited budget, what is the optimum telescope? For an interest-only introductory astronomy course given through an adult education program in Australia, I designed a prototype educational telescope. It had to be 1) informative, in that it taught the basics of designing telescopes, 2) easily constructed from readily available materials with hand tools, and 3) cheap!

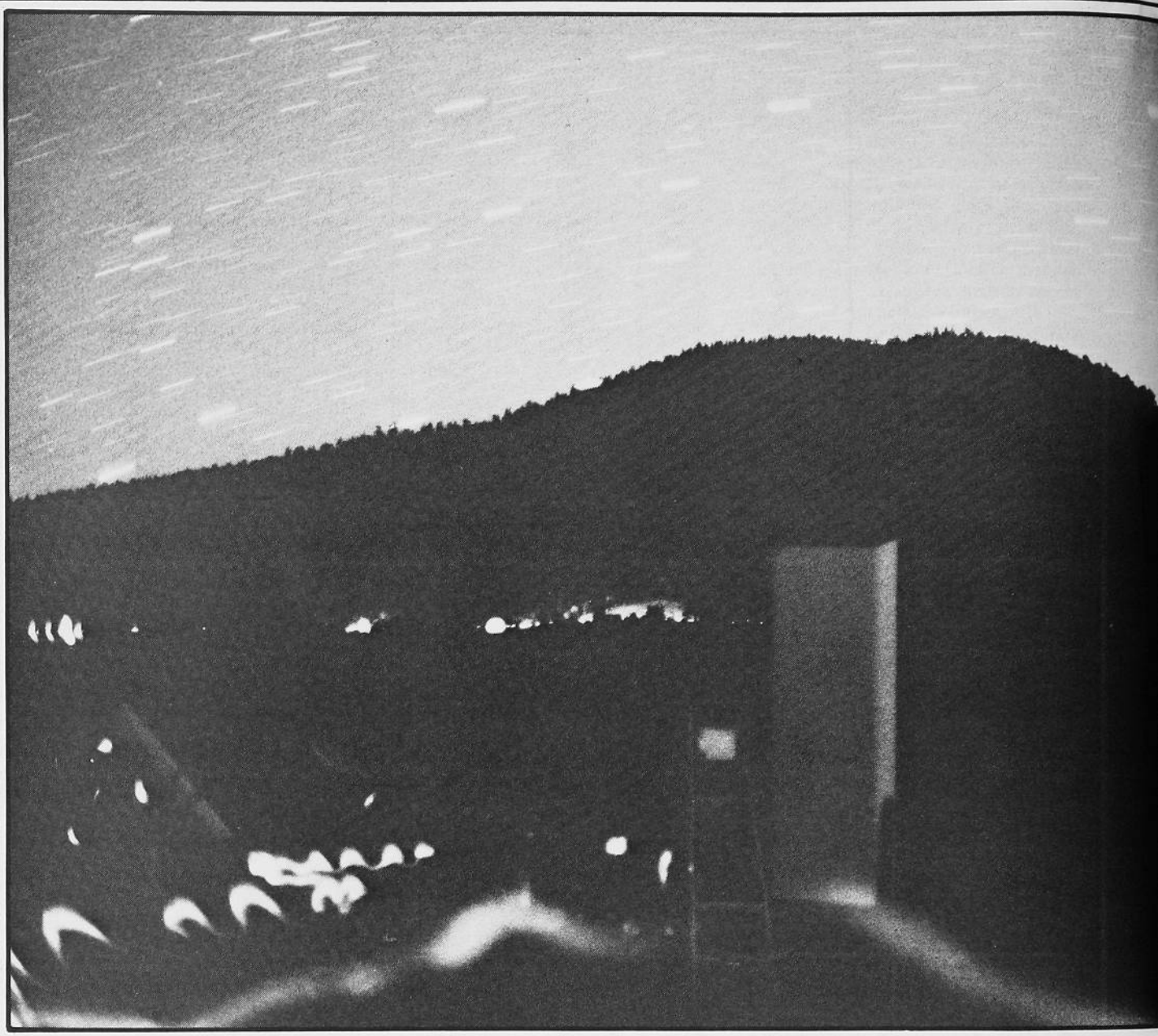
The total cost of the prototype instrument was about $10, including paint. The objective was a 2" diameter +1-diopter spectacle lens costing $1.25. I found that chromatic aberration became troublesome unless the telescope was diaphragmed to 1" aperture. Its optical quality appeared to be comparable with small, poorer quality table mounted telescopes. The eyepiece was a 5x twin lens "Nature Viewer" magnifier costing $ .78. It gave a wide flat field with good eye relief.

In night tests, the telescope, although by no means perfect (after all, a perfect prototype would teach nothing!), proved more than interesting. The Moon came up fine and allowed crater identification, Jupiter's moons and some surface belts were visible, and the celebrated double star, Alpha Centauri, was easily split.

Paying $1.25 for a 1" non-achromatic objective lens seems reasonable in respect to equation 1, which predicts that a 1" achromatic objective should cost $4.00. The total cost of about $10 was pleasing when one considers that the final product should be worth about $33.90 if purchased from a maker.

What does all this portend? This article is to help amateur astronomers. The following points, not generally recognized, should be noted:

- Perhaps more can be studied and learned about the sky with the naked eye than is generally realized.
- Even small optical instruments help greatly — here the 1" aperture $10 telescope comes into its own.
- Very little is to be gained in terms of resolution by purchasing a telescope greater than 6" or 8".
- The Newtonian telescope is by far the cheapest. In terms of stars/$, it's about 1/50 the cost of a refractor and 1/10 the cost of the catadioptric.
- The quality of telescopes varies. Any choice should not be made on objective criteria alone.
- The cost of telescopes and optics appears to have remained fairly constant over the years. They have hence become cheaper, in real terms, with inflation decreasing the value of the dollar. ■



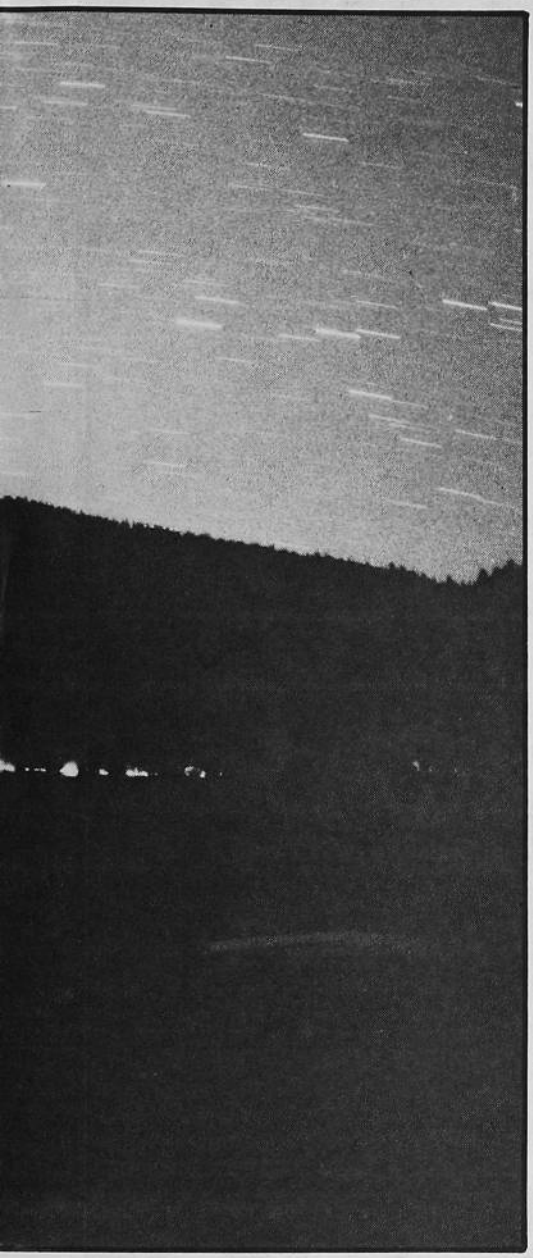
RIVERSIDE

At the junction of Arizona Highways 180 and 64, we spotted our first telescope. In fact, it almost ran me down as I stepped out of the washroom at the gas station there. The plastic wrapped fork-mount rode in a bright yellow trailer, and it was towed by a station wagon jam-packed with dufflebags and tents. The trailer said "Have Telescope, Will Travel" on the rear gate. The car stopped; the driver got out. Half knowing the answer, I walked over and asked "What's a telescope doing out here?"

"We're goin' t' Riverside," said the driver, adding "by way of the Grand Canyon."

"So are we," I said. Norman Butler turned out to be from Kansas, and the telescope was his twin 6" Cassegrain binoculars. That sounded familiar: he had written to me about two months earlier, sending a generous assortment of transparencies of this unique instrument. With him was a whole contingent of Kansas Riverside-goers, and as we talked, they piled out and stretched.

This year, in order to fit our vacation/trip-to-RTMC into a busy writing and production schedule, Ele and I took some vacation first. We flew to Phoenix, rented a car, and, after spending a day with Ele's father (who happened to be in Phoenix on business), headed north toward beautiful red-rock Oak Creek Canyon, and camped. We passed up Meteor Crater with some regrets — so too Lowell Observatory — but with many miles of desert to cross, we couldn't afford more time in the Flagstaff area. It was on the next day, heading north toward the Grand Canyon, that we encountered that other car enroute to Riverside. Despite a gusty wind and an on-and-off sleetstorm, we spent the day sightseeing the Grand Canyon, its red and ochre towers stratified, blued by depth and distance,



'81

immense. I thought of the Valles Marineris on Mars that I had so recently written about — seven times deeper and ten times wider and longer — wondering if such giantism could be more impressive than our own planet's water-hewn and air-veiled "vallis," or whether the sheer scale of such a feature might make it harder to see, and thus less impressive.

As we descended from the 7000-foot altitude of the South Rim, the air grew warmer. The sky cleared, we sped west across the desert, and I wondered what RTMC '81 held in store. If the weather were good, I expected numerous Dobsonians and a good selection of equatorially mounted large apertures, too. Also, I expected to see the most impressive display of commercial equipment, goodies, bargains, prices, and advanced ready-built gear ever to be offered. As Riverside becomes increasingly important for demonstrating and selling new gear, no manufacturer can afford not to be there.

Friday morning, bright and early, we left Barstow, driving across the desert. We stopped twice — once on a small range of mountains and once again near Big Bear — each time botanizing and geologizing among the local flora and rocks. But we were still ahead of schedule (arriving at Camp Oakes before 1 p.m. is "streng verbotten" according to the info sheet). So we drove up to Onyx Peak for a picnic lunch, and arrived at Camp Oakes promptly at 1:01 p.m.

Ele and I chose bunks in Building 20 — a family dorm — and as a hedge against too much domesticity, we set up our little yellow tent in a pleasant grove of trees nearby, on a bed of pine-needles and rocks. As it turned out, the family dorm was fine — except for two electrical fires in a wall socket Saturday night and no hot water for showers the next morning.

Friday afternoon and evening were exciting. More and more TMs rolled in, in cars and vans and campers, unloading one or more telescopes, hurrying to set up. By dusk, there were four or five 16″ telescopes, one 18″ (Kevin Medlock's), and a 22″ (Mike Hatcher's) on the field, plus a dozen or two 10 and 12-inchers. The wispy clouds of the afternoon vanished, the temperature fell, and the stars shone.

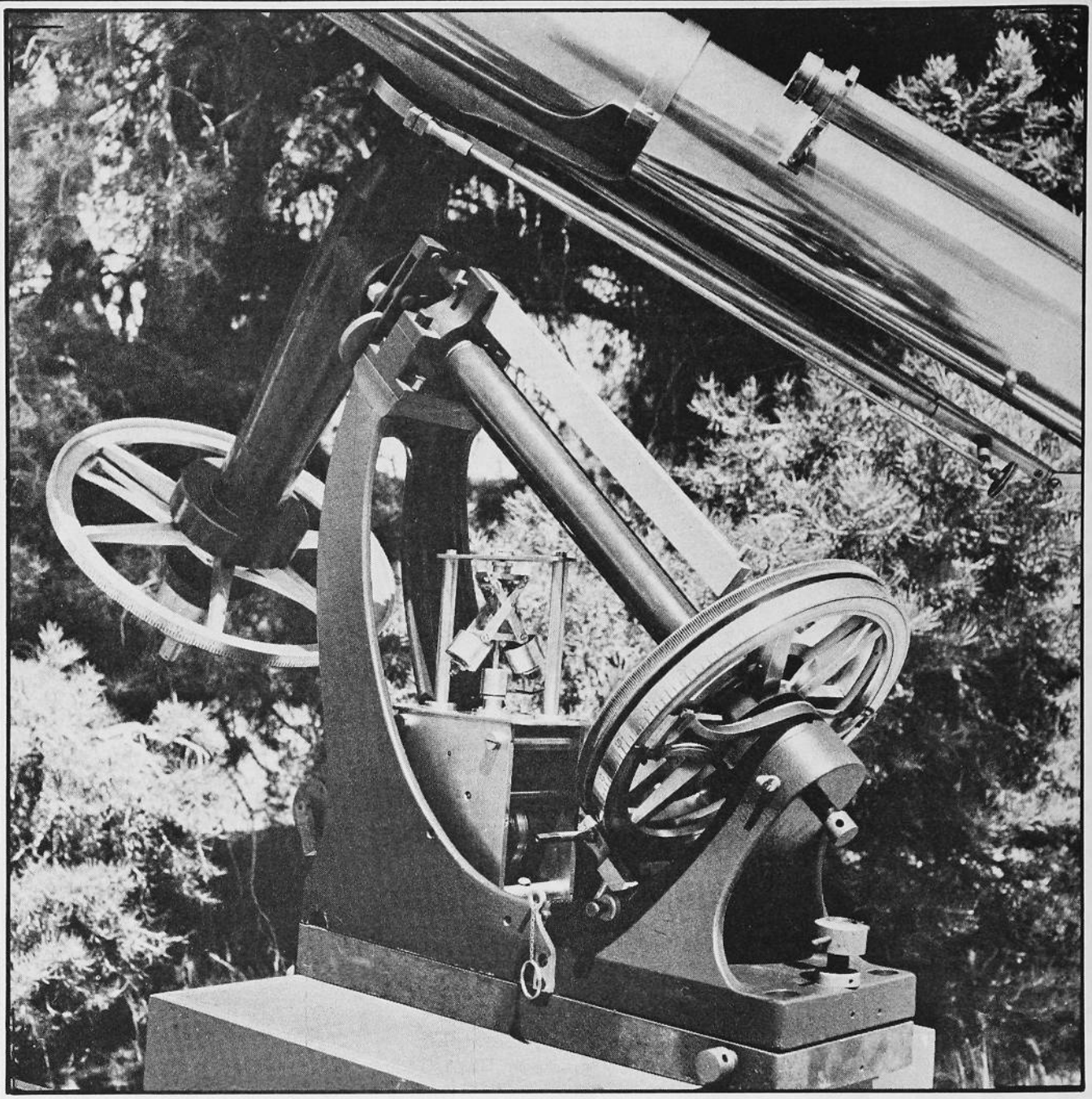
I circulated from one scope to another, seeing all the most popular Messier objects. Uranus was a lime-green disk in a 16″ fork-mounted Newtonian. In Alfred Lilge's 6″ f/40 siderostat, I saw a remarkably sharp image of Jupiter. Did you ever wonder how to find objects in a stationary telescope? He attaches a clip-on finder telescope that points into the siderostat mirror. Mike Hatcher's 22″, now painted white (two years ago it was battleship gray), was tempting, but the line for it soon became so long that I stuck to using the 16″-ers.

I borrowed a tripod for my camera and began a series of time exposures of observers and telescopes. However between what I considered excessive use of flashlights (jeez guys, turn 'em off and get dark adapted instead) and the headlights and tail-lights of cars, it took many, many exposures to obtain just a few decent pictures.

A little before moonrise, I went to the main building to warm up and there I met Pete Manly. Two years ago, Pete was

working with a CID camera. He still is, but now he lives in Tucson instead of San Jose, and he's attached a CID to a second generation image intensifier (the intensifier part of such a device now costs only about $1500, more for one with an eyepiece and objective lens). When we left the hall, I tried the tube on the sky. At approximately 2x magnification (and perhaps 500 gain in light intensity), I could see thousands of faint stars, to about ninth magnitude. M-51 appeared as a fuzzy spot, as did M-13 and its two flanking stars. Pete said some people strongly object to the scintillation in the tube, and don't like image tube viewing for that reason. I find scintillation a good deal more ignorable than snow on a TV screen.

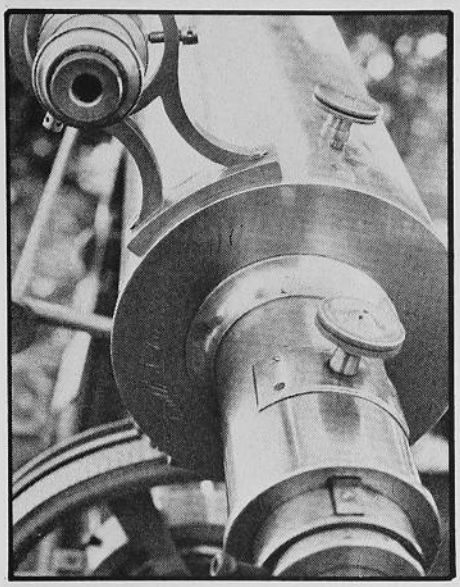
It was midnight, and the Moon was up, so I went back to the dorm and turned in.

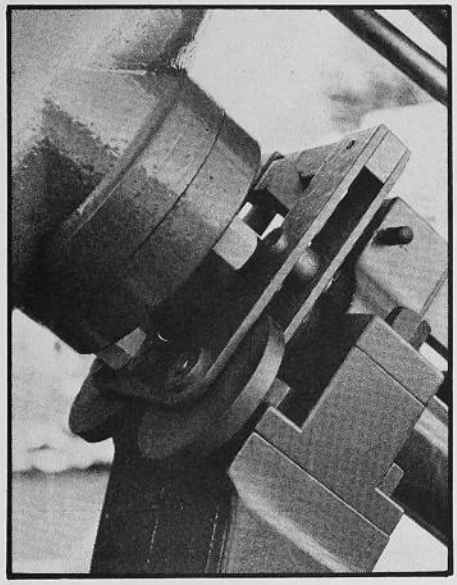


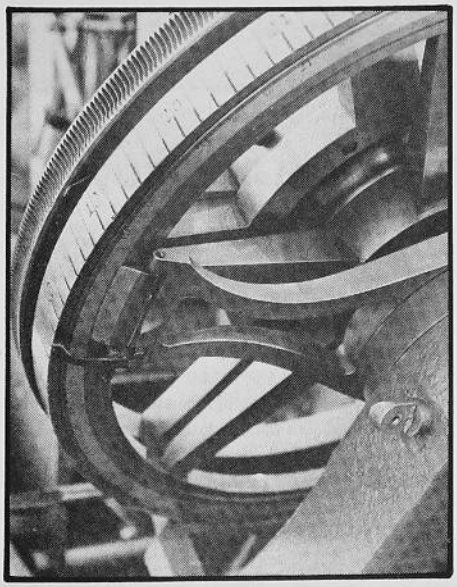
setting circles: the old way. . .

Pat Michaud of Yucaipa, California, has had the priceless opportunity to restore a fine brass refractor. He received it at Christmas, from his wife, with the stipulation that if he didn't want it, it could be returned! The only problem was that it was completely disassembled, and there were no directions with it.

The declination circle is 16″ diameter, RA is 12″. Both have a finely-engraved inlaid silver scale. In RA, the scale reads single minutes and the vernier reads in seconds. Dec runs a full 360°. The tube is 74″ long and apparently once held a 5″ to 5.5″ objective. The instrument is weight driven, controlled by a governor, and the north polar axis bearing has a weight-compensating mechanism. Pat would appreciate any information on the maker of the instrument ("Fauth & Co., Washn, D.C." is engraved on the tube). Write Pat at 12753 10th St., in Yucaipa, CA 92399.







The next morning, breakfast was a crowd scene. I needed a cup of coffee desperately in order to begin functioning. As I maneuvered my plate of eggs through the throng, I heard a call from the Tucson contingent, and so came to sit next to a distinguished looking older man. He looked at my name tag, and promptly introduced himself as Bart Bok. Alas, he said, in Los Angeles someone had stolen his lecture slides! Difficult to replace! Unique! The thief must have thought the slides were jewels! And they were! Maybe someone would find them! What a whirlwind of energy he was — I felt like a lump of inert flesh. Before I could even ask, he offered to write an article for ASTRONOMY, and expressed his liking for that magazine at great length. Ele got us coffees, so I drank mine and wished I were awake enough to respond better.

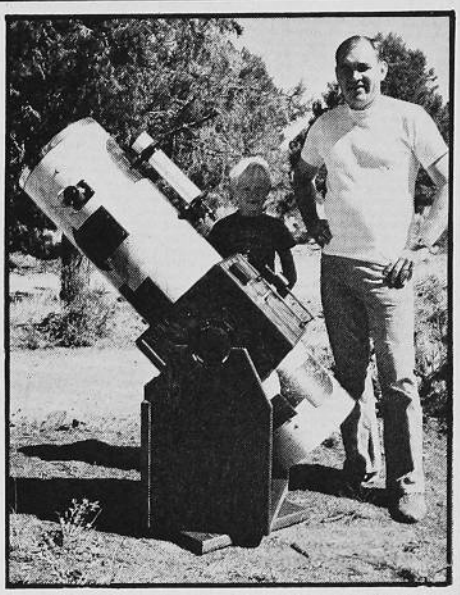
I had hoped to hear about half-a-dozen of the talks, but instead I spent all morning and afternoon roving the field to see all the telescopes. (By the way, each year the Orange County Astronomers publish the talks as a booklet, which may be obtained from them.) Walking the field, every time I'd come back to any given spot, there seemed to be more telescopes there. Attendance seemed to be rising with amazing speed. I talked to people, took notes, took pictures, discussed how this thing worked and how that thing had been made.

Looking at a mount that looked entirely non-commercial, I asked "How did you make this part?" To me it looked like a milling machine job.

"Oh, I cut it on a bandsaw, then filed it smooth." The workmanship and care that go into such telescopes are always a pleasure to look at, especially when someone working in his basement can do work that looks like it came from a big machine shop.

Then there are Orien Ernest's telescopes. He has a way with metal: welding, drilling, filing, into soft sculptural forms that make aluminum seem like wax. The designs are fiendishly clever, too. And, to cap it off, the photography he does with his telescopes is superb.

Of the commercial exhibits, I gave Dick Nelson's surplus operation the most careful look. Last year I bought a magnificent surplus finder from him for $25. This year he had orthoscopic eyepieces for $7, in three focal lengths (someone's close-out), the usual run of aerial camera lens, lots of oldish cameras, and several microscopes. One in particular looked very solid and professional. It had three objectives, a substage condenser and diaphragms, coarse and fine focus, and a massive stage. I looked it over carefully — then, well, I agreed to buy it.



Steve Kysor has applied a little trig (via his TRS-80 pocket computer) to calculate (A,Az) from (RA,Dec,ST) for his 10″ f/5.6 Dobsonian. Watch for his article next TM.

. . . and the new.

At 3:45 in the afternoon, the Swap Meet began. There were riches to be had in used equipment, old magazines, dead cameras, lightmeters, mirror cells, whole telescopes, and out-dated or blemished commercial products. I found a thick NASA book of Ranger 9 photographs, a big chunk of Teflon, and an 8x50 finder that some manufacturer seemed to be phasing out.

As the evening fell, everybody gathered in the meeting hall for the first drawing of door prizes (chairs from Questar, Star Atlas 2000.0 from Sky Pub, observer's flashlights, etc.).

Then came Bart Bok's talk. Even without slides he was magnificent, witty, as he presented his views on the Milky Way and the immense expansion, and changes, in our picture of it in the last few years. He stressed the major points carefully, admonishing the audience: "If you remember nothing else, get *this* one fact into your noodles."

After his talk, I joined the big star party on the hill until clouds rolled in and I found myself half-asleep on my feet.

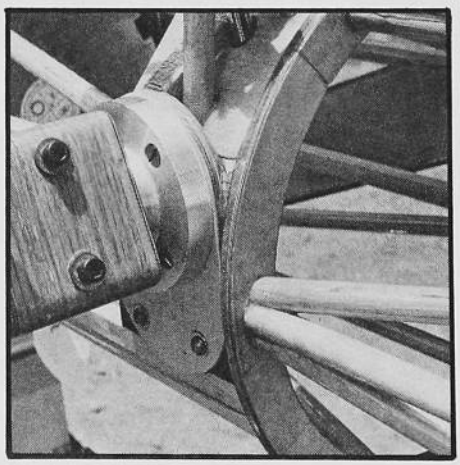
On Sunday morning, I participated in a panel to answer questions about telescopes. After breakfast, we met in a small arena called the Fire Ring, out behind the swimming pool. The first question was to Jim Jacobson of Coulter Optical: "What is the delivery time for a 17.5″ mirror?" He said it's now 6 months, explaining that the demand had been about four times what they'd anticipated, and that the long delivery times for grinding and polishing machinery to make big mirrors had caused many delays. Other panel members fielded

wood as construction medium...

This adaptation of the Springfield design in ATM Book 2 was built by Tim Parker of Huntington Beach, California. The 9-sided tube is made with Indian rosewood ¼" plywood, bulkheaded and fiberglass reinforced internally, and carries an 8" f/6.3 mirror. The diagonal mirror measures 2.6" across its minor axis. Parts for the mount, made of ½" aluminum plate, were fabricated using bandsaw, drillpress, and handtools, although some of the drive parts were machined. It uses a 5.75" worm gear. In the declination bearing, the aluminum plates simply slide on thin brass rings.

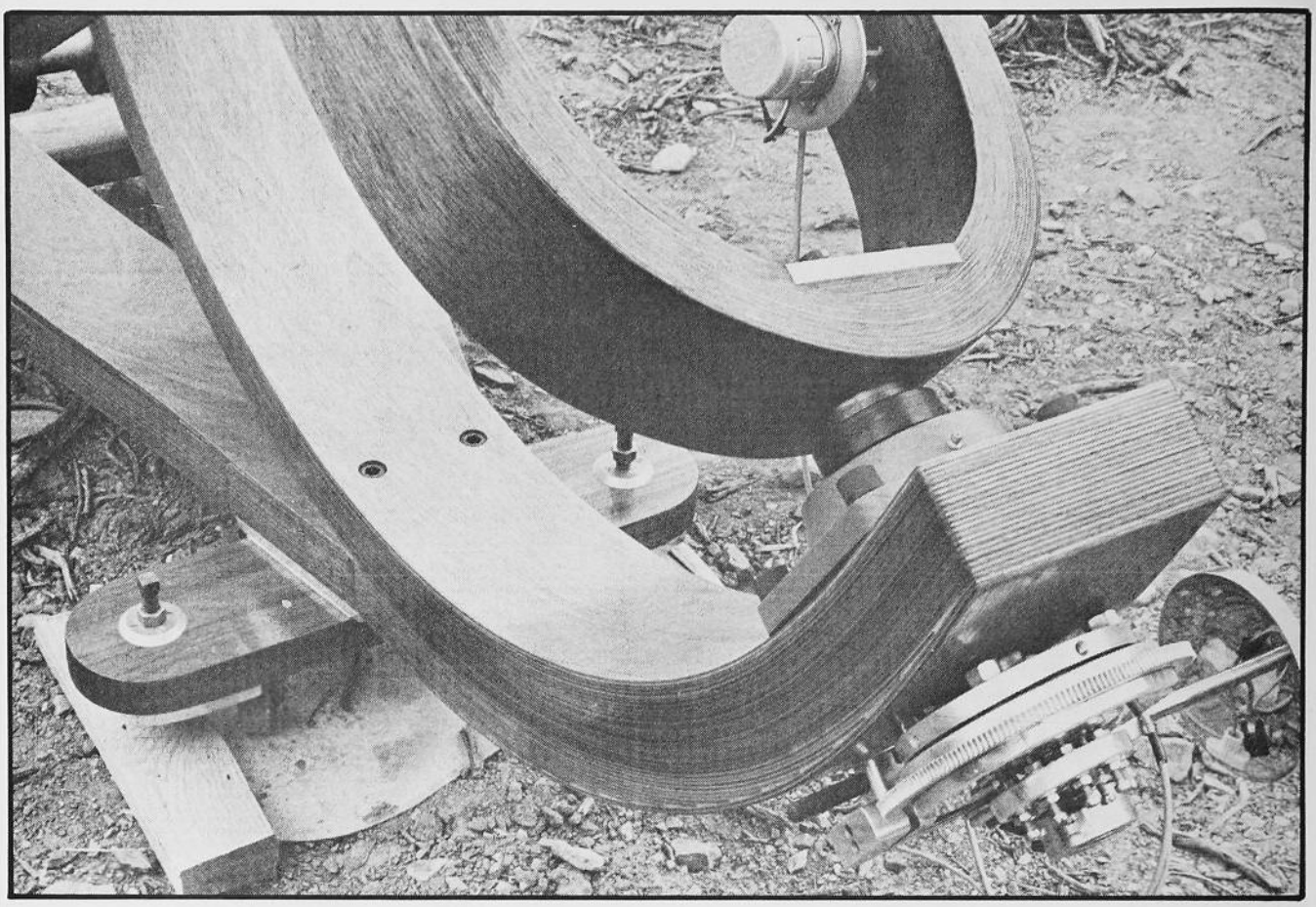
Note the handy position of the finder near the main eyepiece. It is protected by passing through the counterweight arm. The tripod is an adaptation of the tripod described in Texereau's book. The counterweight, 22 pounds, is too heavy and will be replaced with a lighter one. Just imagine sitting at the eyepiece!

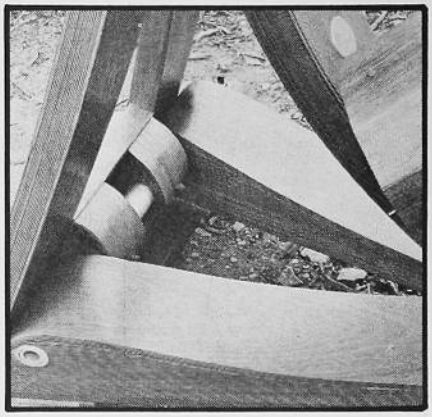
. . .beautiful, light, and rigid.



Down near the lake sat an 8″ f/6 open-tube telescope that looked, from a distance, like a machinist's delight. But up close, it held some surprises. First, this instrument is constructed largely from birch aircraft plywood, and finished in its natural color with marine spar varnish. Second, it is an amazingly solid telescope — with none of the shimmy that marks underbuilt mounts. Thirdly, the integration of machined metal parts with wood is beautifully handled, so both materials appear to belong.

The builder, Tom Greska of Lawndale, California, said he spent 350 hours constructing the telescope, and spent about $650 for materials. Some of the material was free, however, such as the boat teak base given him by a friend. The fork uses staggered lap joint construction, and is hollow inside. It is driven in both axes; in RA by a 6″ Byers drive, and in dec, by a tangent arm.





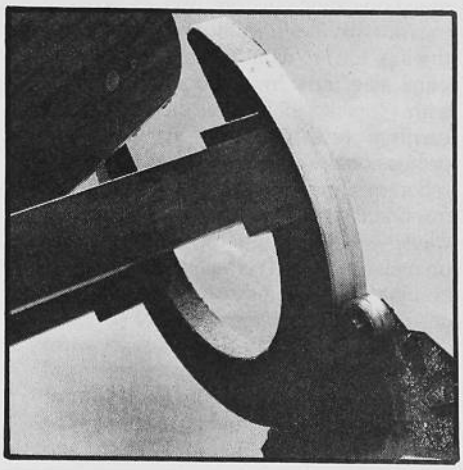
yoke mounts. . .

Weyman Reams of Santa Monica, California, crafted this telescope tube and mount over a period of many years. The telescope is an 8" f/8.3 Newtonian reflector mounted on a one-piece wood yoke supported on piers molded in sweeping curves. The 12-sided mahogany tube is about ¾" thick; the mount is laminated from 1/16" layers of a deep ruddy-brown wood into a 3x8 inch cross-section. Some metal accessories are chrome plated, while other parts still bear the original factory paint.

. . . executed in wood.

Complementing the curved form of the Reams telescope was the squarish form of Larry Stancil's 12.5" Cassegrain in a horseshoe yoke mount. Normally mounted on concrete block piers at the San Diego club's site in Tierra del Sol, it was mounted on ½" fir plywood piers at Riverside. The yoke and tube cradle are made of birch ("birch is very rigid and it damps fast — besides it's easier to work than metal"), and the horseshoe yoke was cut from four glued layers of ½" plywood with a router and wrapped with an aluminum band. It runs on rollers placed in the north pier. The portable wood piers are bolted together with 2x6s at the base.

The tube, which looks like wood, is actually made of wood-grained formica rolled into a tube. Drives on both axes use Byers gears. Setting circles are illuminated. The considerable storage space available in the piers is used for housing the drive oscillator and eyepieces.



1981 Riverside Merit Awards

ORIGINAL DESIGN
Walter Clark
Fullerton, CA
"Omnitorial" Mount

JUNIOR AWARD
Chuck Bennett
Poway, CA
10" f/5.6 Dobsonian

WOODEN MOUNTING
Laurence Stancil
San Diego, CA
12.5" f/16 Cassegrain Yoke Mounting

DESIGN APPLICATION
Tim Parker
Huntington Beach, CA
8" f/6.3 Newtonian
on Springfield Mount

BEST OBSERVER'S ACCESSORY
Ray Courchie & Steve Edberg
Los Angeles, CA
Spectrograph

BEST CORONAGRAPH
Dennis Gallagher
San Leandro, CA
4" f/31 Lyot Coronagraph

INNOVATIVE IDEA
Rick Shaffer
Altadena, CA
18" f/4 Newtonian on Cam-controlled
Dobsonian Mount

EXCELLENT WORKMANSHIP
David Piton
Sacto, CA
12.5" f/5 Newtonian

BEST WOOD DESIGN
Weyman Lee Reams
Santa Monica, CA
8" f/8 Newtonian on a Laminated
Wood Yoke Mount

WOOD CRAFTSMANSHIP
Thomas Greska
Lawndale, CA
8" f/6 All-Wood Newtonian

STABILITY
Perry Genis
San Bernardino, CA
10" f/4.5 - f/15 Newtonian/Cassegrain
on a one-armed fork mount

ENGINEERING DESIGN
Norman Butler
Manhattan, KS
6" f/15 Cassegrain Binoculars

WARREN ESTES AWARD
"for the best use of simplest materials"
Dick Houskeeper
for
The World's First Astrophotographic Dobsonian

THE CLIFFORD HOLMES AWARD
"to the person who has done the most
for amateur telescope making"
to
Richard Berry
Given jointly by Richard Poremba and Luther Davisson
of Astronomy for America
and
The Riverside Astronomical Society
Plaque plus a check for $100

questions ranging from how to polish a mirror with a central hole (put a hole in the lap, too) to what is the best RFT exit pupil size (not 7mm, but about 5mm), with topics including diamond-point turning (it's coming, at least for professional opticians), f/4 versus f/8 reflectors (inconclusive), how important fractional-wave optics are (better than ¼-wave — but how much better remained unanswered), and removing old coatings (1 pint HCl + 1 teaspoon $CuSO_4$ per gallon of water; use at 75°-80°F).

Sunday was a day to relax, with warm temperatures and plenty of sunshine. I spent a long time talking to Bob Kestner about his series on grinding and polishing thin mirrors (beginning in TM#12), and perused the commercial exhibits that seemed to fill about half of the parade ground field. Every year, commercial equatorial mounts are get bigger and more solid as people become willing to pay the price for stability. Telescope World's massive mount (they had a 16" on it) seems to resist thumping quite well. The new, very solid Byers 812 was on display on its stubby rock-solid tripod. A new company (K.K., I think) had a massive and beautifully finished mount there, for about $3,000. Tom Mathis was selling drive gears from the back of his pickup truck and giving people advice on drives.

Meade had a telescope on display. Celestron was present with a C-11 and a stock of molded mirror blanks, complete with defects for "low, low prices", and Questar had one of theirs set up near Pat Michaud's refractor. Plenty of other firms were there, too, thanks to the concentration of both big and little telescope firms in Southern California.

One of the more beautiful scopes I saw was off to the east of the parade ground among the trees, a Springfield made by Tim Parker. Its nine-sided Indian rosewood tube looked dark and rich. This was a telescope I wanted to look through — the promise of observing while sitting down is hard to beat. Tim gave me some tips on making polygonal tubes out of thin plywood, something I've wanted to make for a 6" refractor

objective I got years and years ago.

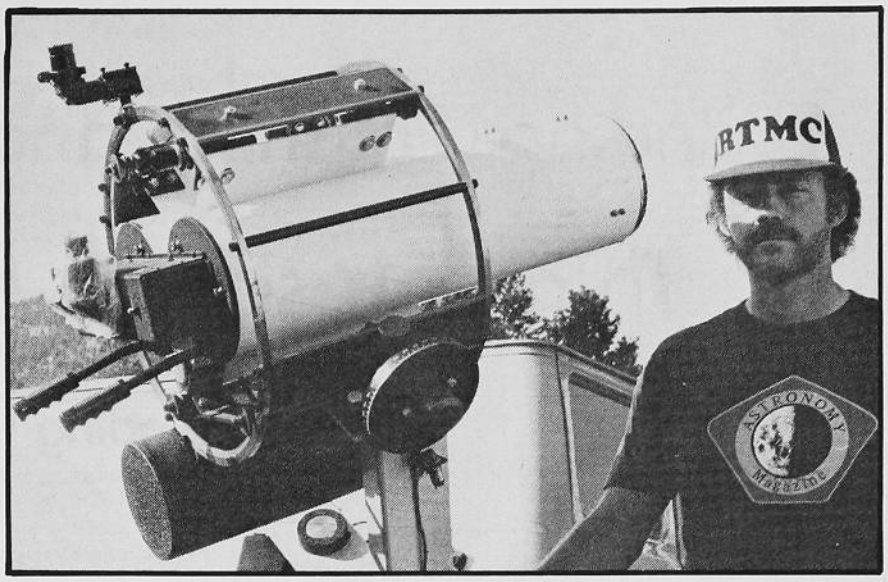
After dinner as the darkness approached, we gathered in the meeting hall for the presentation of merit awards and drawing of the second group of door prizes. Cliff Holmes first thanked the Riverside and San Bernardino Club members who had contributed to the success of this year's meeting; then members of the Merit Awards Committee announced the award-winners (see the table at the end of this article), one by one, giving each a brief citation with the award. Then came the Warren Estes Award, to Dick Houskeeper, for his photographic Dobsonian, a tribute in the name of one of the founders of RTMC for effective use of simple material.

I was taking notes, of course, for this article. Suddenly, or so it seemed to me, came the announcement of the Clifford Holmes Award — and *my* name was called. I was stunned. David Levy, sitting next to me, or Ele, sitting on the other side, said something that brought me back — and I stumbled over people's feet and to the front to accept the award from Luther Davisson of Astronomy for America. I felt the weight of the heavy plaque in my hands, but was utterly speechless. I said thank you, then managed somehow to return to my seat. (Since then, I have collected my thoughts. See the editorial in this issue.) Then the door-prizes were drawn, including the three complete sets of TM back issues that AstroMedia was giving.

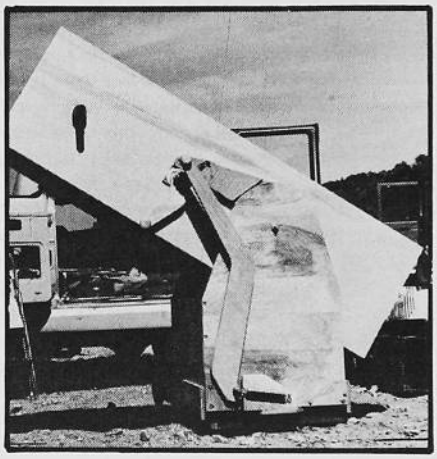
Exhausted, congratulated, hand-shaken, we returned to our dorm. After a while, since it was cloudy, we cleaned up a bit, and went back for the end of *Dr. Strangelove*. After the movie, we had hot chocolate and cookies, and talked with Patty Winter, Steve Greenberg, and Pete Manly about computers, electronics, and their future in astronomy. As we walked back to our dorm for the second time that evening, I noticed a few stars twinkling in the northwest. Thirty minutes later the sky had cleared, so I put on my down vest and anorak, then walked back up the hill to the telescope field.

Under the stars Sunday night, the lines were short. I tried the Springfield telescope and found sitting as I studied Jupiter's belts most pleasant; then I walked up to Norm Butler's twin 6″ Cassegrain binoculars to try them on the same object. The effect is amazing: the moons seem to float three-dimensionally in space around the planet.

As Scorpius and Sagittarius rose in the southeast, I gravitated toward Mike Hatcher's 22-incher and viewed the Omega Nebula and some of the bright southern clusters. Then, for comparison, I tried the Cherringtons'



Stay tuned for the next several issues. Above: Norman Butler's 6″ Cass-binocs. Lower, left: Dick Houskeeper's photo-Dobs on a Poncet platform. Lower, right: Rick Schaffer's 18″ with cam controls.



"Evergreen," a 16″ Dobsonian, for a few comparisons. There is not, in truth, much difference between a 16″ and a 22″ — just more light in the 22″. Both were limited by the mediocre seeing. It is odd to reflect that ten years ago, 16″ telescopes were still a rarity. At Riverside this year, there were at least a dozen, plus two 17.5″-ers, an 18″, and a 22″.

Monday morning was taken up with goodbyes, lots of "See you next year!", my finding a few people with a: "Let me get a picture of you and your scope before you go." Ele and I struck our little tent, rolled up the sleeping bag, packed our new microscope, my bar of Teflon, a new eyepiece, the Ranger 9 book, the 8x50 right-angle finder telescope, plus pinecones, the exotic-rocks-from-Arizona, and all our dirty clothes, our heavy sweaters in-case-it's-cold-again-this-year, and a dozen exposed rolls of film, loaded it all into the car, and drove off.

What will we see next year? It is difficult to second-guess the trends in telescope building. Gearless drives could increase in popularity — or a system like the Byers 812 could render them superfluous. Fork mounts may become more common, or the apparent difficulties in making a fork solid could halt their growth.

Will the trend toward Newtonians continue — or will more builders try TCTs or other exotics? Will S-CTs continue to be marketed so successfully despite their relatively high price? Might refractors ever make a comeback? Are there any good designs not yet thought of? Will the trend toward larger and larger apertures halt — as sooner or later it must? Where will it halt? Will we see 24″+ amateur telescopes become a fixture at every major gathering? Telescopes will become bigger, I am sure, but what is "too big"? Where will amateur astronomy go from there? Might next year be the year someone shows off a cheap and practical L³TV system? These thoughts passed through my mind, as miles and miles of freeway rolled by.

— *Richard Berry*

Grinding, Polishing and Figuring Thin Telescope Mirrors

Part I — Grinding

For many years, amateur astronomers and telescope makers thought it essential that glass for telescope primary mirrors be at least one-sixth as thick as its diameter. In the last decade, however, it has become increasingly common to find telescopes with primary mirrors very much thinner than the standard 6 to 1 ratio giving excellent optical performance. In fact, the trend has now gone so far that it is unusual to hear of an amateur telescope project much over 12″ aperture that has a standard thickness mirror.

Why has this happened? Is the 6 to 1 ratio a myth perpetrated by opticians of a past generation to obstruct the building of large amateur telescopes? Is the 6 to 1 ratio somehow wrong? The answer is no, it is not wrong — it has just been misunderstood. In the optical industry, 6 to 1 is a good compromise between making the glass so thick that flexure can almost be ignored, and making the glass thin but spending much more time and money seeing to it that the glass does not flex and will hold its figure in use.

The avid and somewhat uncritical acceptance of standard-thickness glass in the early years of telescope making — plus some notable failures with thinner glass — gave the general impression that telescope primaries much thinner than 6 to 1 were unmanageable. They are not, but without using the proper techniques, they can be extraordinarily difficult to figure.

However, with the right techniques, thin mirrors aren't much more difficult to make than ordinary mirrors, and for the purpose of large amateur telescopes, thin primaries are advantageous. They are less expensive than thick primaries, are lighter and easier to lift (more important than one might think at first), add less mass to the telescope, and equilibrate to temperature changes more rapidly.

Preparation

The purpose of this article is not to teach you how to make a telescope mirror if you have never done it before. If you have made mirrors before, it can guide you in adapting the techniques you already know to the problems peculiar to big, thin mirrors. But I offer this warning: if you have never made a mirror before, don't start with a large, thin mirror. It's a bigger job than you realize.

There are many different ways of grinding mirrors. The methods I describe are those I use when working at home, grinding and polishing entirely by hand. Where I refer to machine working, it's for your information, and not essential to making a successful mirror by hand.

The techniques described in this article are for mirrors of 16″ and larger. Again, I consider it essential that anyone attempting a mirror of this size on his own must have made at least 2 mirrors successfully before, unless he or she possesses an extraordinary aptitude for optics.

Obtaining Glass

Obtaining glass is often a problem. As of this writing, there are no companies supplying thin mirror blanks to amateurs. Until somebody recognizes that there is money to be made supplying the glass, telescope makers will be forced to buy rough cut glass from glass companies not used to selling small quantities over the counter.

It will take some tact and understanding on your part to deal with these places, to outline what you do need, as well as what you don't need from them. Remember, if you tell them what it's for (people love telescopes — promise them a look through it), many businesses will bend over backward to help you. But don't expect them to — they'll probably lose money on you.

There are still places where you can obtain plate glass portholes. Try surplus stores in coastal cities. Many 16″ and 18″ diameter portholes 1″ thick are still out there, ranging in price from $10 to $150 (1981). A reasonable price is whatever you're willing to pay. The problem is finding one.

Pyrex Sheet Glass

Pyrex sheet glass is available from those glass companies not used to selling to amateurs. Corning makes Pyrex in many different thicknesses, the thickest now available is 1.62″. They sell it to glass companies (Corning distributors) in large square sheets. If you can't find it locally, try getting quotes from Bi-Optical in Costa Mesa, CA; from United Lens in Anaheim, CA; or United Lens in Massachusetts.

Most companies sell coarse annealed and fine annealed. I recommend fine annealed for telescopes. I don't know if coarse annealed would suffice because I've never tried it. It's probably a hit-or-miss thing — most will work and some may fail.

The prices for sheet glass vary quite a bit. The last time I checked (late 1980), pieces 16″ diameter by 1.62″ thick

were about $225, and 24″ diameter by 1.62″ thick were about $500.

When you order from a company, specify the diameter (rough round) and thickness. They'll cut out a square piece on a saw that will yield your diameter. Then they cut off the corners several times until the piece is round. What you'll get is a piece of glass blank with 16 to 60 sides with the surfaces only roughly flat — to less than ⅛″. Be sure to insist they cut lots of sides — you don't want just 8.

Next, you'll have to contrive a way to grind the blank round and flat. Grinding it round is not very difficult, especially if your piece has enough sides — it's just a matter of grinding off the high spots. I use a hand-size piece of tile and #80 grit. Grinding by hand against the outside of the glass, I've made a 16″ with 30 sides presentable in 2 or 3 hours.

The surfaces are not as easy. You must grind both flat — especially the back. This can take 20 or 30 hours per surface on a 16″ if you're working by hand, but the grinding time may be much less depending on surface quality.

If you're lucky, you may find a company willing to diamond-generate your blank. They can Blanchard the back flat, edge it round, and generate the radius. This work on a 16″ will run $100 to $200. The problem is finding a company willing to do it. Work of this sort is usually done at your risk — if your glass breaks, you've lost the blank. Although glass breaking is uncommon, chips occur more frequently. All these problems may seem insurmountable, but TM is constantly publishing information about suppliers, so some firms dealing with amateurs may eventually turn up. Until then, you will have to use your own resources. Someone possessing the ambition to make a large telescope mirror can probably overcome these supply problems with a few dozen phone calls and letters. When you succeed, let TM know about your results so others can gain from your experience.

Thin Pyrex versus Thin Portholes

I was going to skip this section and leave it to your discretion, but the subject can't be avoided. It's paradoxical that something inferior (i.e., porthole glass) works as well as something better (i.e., Pyrex), given reasonable circumstances.

Plate glass has a three times greater coefficient of thermal expansion than does Pyrex. It should, therefore, be worse for telescope mirrors than Pyrex. Yet, when a plate glass mirror is used in a solid insulated tube with a closed back (such as a big Dobsonian), after initial equilibration in the evening, temperature changes in the mirror are quite slow. The telescopes that I've observed with most have plate glass mirrors mounted in closed-back tubes, and I can testify that the figure change after equilibration during the night is quite small.

If the back of the mirror is directly exposed to the air, temperature changes in the air affect the mirror more directly. At times I've been annoyed with the changing figure of a plate glass mirror under these conditions.

A crucially important fact, however, is that portholes come round and 99% of them have surfaces flat enough to start grinding the curve right off. With Pyrex, you must start by making the surface flat, which is a lot of work.

Now the bad news! Plate glass is more difficult to figure than Pyrex, and sometimes the strain in portholes is not negligible. Figuring plate glass is more time-consuming and more tedious than figuring Pyrex. After you attack a plate glass mirror with a warm pitch lap, it's several hours

before you can tell anything about the progress you've made figuring. That means when you're doing the final figuring, you'll wait three hours before you can test the mirror to see what needs to be done next. Considering the time it takes to get going again, it can take all day to work the mirror twice. If you plan on making a porthole mirror, don't let this stop you: just recognize it is plate glass, and allow for it.

Well, there it is. Pyrex is easier to manage than plate, but it takes much more work to get a sheet glass blank ready to grind. The choice is yours. These days, I work only Pyrex, but I can afford to discriminate. I can buy it easily and get all the starting work done on diamond-grinding machines — something most of you don't have access to. I've also figured a half-dozen plate mirrors larger than 16″ and wouldn't trade the experience for a million dollars — not to mention the thousands of hours of excellent observing these mirrors have given in return.

How Thick

The thickness you choose, if you have a choice, is determined by the diameter of the mirror and how you plan to mount the mirror in the telescope. For mirrors under 19″, I would not use glass under 1″ thick; and if you're buying Pyrex, I'd use a 1.62″ sheet.

For mirrors in the 20″ to 25″ range, I'd strongly recommend 1.62″ as a minimum thickness, especially if the mount is not going to be mounted in a sling.

Last summer a friend and I made a 25.5″ mirror on a 1.37″ thick Pyrex mirror. The curve, f/6, was relatively shallow. We paid strict attention at every step of the way to prevent flexure, especially when testing the mirror in a vertical position. I remember wishing that we had had that extra .25″ in thickness. On the other hand, when it turned out well, it seemed good to have a 25″ mirror that could be carried with little trouble.

The 1.62″ is just a recommendation on my part, since it allows you a little room for error especially in a 16″ or 18″ mirror. For mirrors around 30″ in diameter, working by hand, 1.62″ is the minimum thickness that I would consider. If you plan on working your mirror by machine, you'll run into problems that will increase the minimum thickness needed even more.

Choosing the Diameter

I recommend that you start your big, thin mirror career with a 16″. By keeping your ambitions relatively

modest, your chances of success are much higher than with mirrors over 20". Even though my current efforts are going into a telescope twice as big as a 16", my observing friends and I agree that we could live the rest of our lives happily observing with a 16" without the slightest regret.

In choosing a blank size, you should think of the outer ¼" of your mirror as lost to a turned edge. You won't be alone in this — most big mirrors have a clear aperture at least ½" less than the blank diameter. If you find a 16.5" porthole, think of it as a finished 16" mirror. If you're buying sheet glass, add ½" to the diameter of the finished mirror you want.

Choosing the f/ratio

After the aperture, you must choose the f/ratio. The most important factor from the standpoint of an optician is that a longer focus mirror is easier to make, since it departs less from a sphere. From the observer's standpoint, a long focal length makes a big telescope too big! Unless you have an army of people to help you set it up, you should not let the focal length get out of hand. Don't minimize the problems of simply using a telescope longer than ten or twelve feet — you'll spend a lot more time clambering up and down the ladder than you ever dreamed.

At the lower bound of useful focal ratios, coma and eyepiece aberrations limit your mirror's performance. Furthermore, short focus mirrors — or at least good quality short focus mirrors — are very difficult to figure, and as a further practical consideration, remove valuable thickness from your glass.

My recommendation is to play fairly conservative, and choose a focal ratio between f/5 and f/6 depending on your circumstances and desires. For most observers, f/5 may be the best choice.

Solid Tools

In addition to finding a blank for the mirror, you will need another disk for a grinding tool. It may be either a solid glass tool or a plaster tool covered with hard ceramic tiles — once again, your taste, energy, and previous experience will dictate what you want to try.

The tool need not be as large as the mirror. You can use a tool 75% of the mirror diameter without too much difficulty. Tools smaller than 75% have less tendency to produce a spherical curve during fine grinding. Although a 16" tool works well with a 16" mirror, for larger mirrors I would recommend a smaller tool simply because full size tools are heavy and awkward.

Usually, what is available dictates what tool is used. Take care, however, not to use a tool that's too thin. If the tool is too thin, it will bend while you are grinding, presenting two problems. First, astigmatism in the mirror will not completely grind out because the tool will conform to the astigmatic contour. Second, the weight of your hands on the back of the tool will force the center of the tool to grind harder on the center of the mirror, generating a curve deeper (i.e., more parabolic) than spherical curve. Usually this is not a severe problem, but you'll find the mirror requires extra polishing to polish out the center.

A 16" tool with an edge ½" thick is approaching a thickness where troubles start. A friend of mine recently used a 16.5" glass tool slightly thicker than this safely. However, I once used a 20" glass tool ⅝" thick at the edge, and got a bad case of astigmatism. We ended up pitch blocking a 16" diameter porthole ¾" thick to the back of it, and then it worked well. While ¾" would be a reasonable minimum for a tool this size, with either plaster or aluminum tools, a thicker minimum should be chosen.

There are two main types of grinding tools — solid and segmented. Solid tools are usually glass and segmented tools are usually plaster faced with ceramic tile.

A solid glass tool can be a disk cut from sheet glass, as you are used to, or can be made by laminating thin plate glass disks together. You can buy circular plate glass from retail window glass companies. You may have trouble finding a piece thick enough to serve as your tool face for rough grinding — you do not want to grind through it into the next piece. Although it has been done, it increases the chances of scratching in fine grinding.

For grinding the flat surface on the back of the blank, just glue on a new piece of glass if you grind through the first. Aquarium cement is readily available and sticks to glass.

Segmented Tools

For mirrors with the curve already generated, or for those wishing to try a segmented tool, a ceramic tile grinder is the answer. Tile tools are made by blocking ceramic tiles onto a support. Such tools can be made flat or curved to fit a generated blank. The tile support can be plaster, aluminum or glass. Epoxy or hard pitch is used to glue the tiles in place. The greatest problem with pitch is that the tiles may fall off in rough grinding.

A plaster support is made by wrapping a metal or cardboard dam around the mirror a couple of inches high. Smear soap over the surface of the glass to keep the plaster from sticking, then pour on the plaster. If the mirror has a curve, this method will give a mating curve on the plaster.

I highly recommend Kerr Dental plaster, Vel-Mix Stone Pink. This stuff hardens like stone! (Call Kerr Co. at 313-946-7800 and ask them for the name of a distributor in your area. They have 400 distributors nationwide. It costs $12 for 25 pounds.) Add water to it and stir until it is slightly thicker than cream.

Almost any unglazed ceramic tiles will do for the grinding surface. They should be around 1" to 2" square or round. Attach them with epoxy. Epoxy can be bought in cans at hardware stores. It helps if you can buy an epoxy softening agent, making the epoxy less brittle.

To epoxy the tiles to the base, start by protecting the mirror surface. Smear a release agent on your mirror so that excess epoxy will not stick. (Buy the release agent with the epoxy — but I suspect grease or soap would work, too.) Place the tiles in the desired pattern on the mirror. Space them no less than ¼" apart. Pick them up one by one, and spread a thick coat of epoxy on them. Set them back in place epoxy side up. It is a good idea to get a friend to help you, because you must coat the last tiles with epoxy before the first ones set. After they're all coated, carefully set the support onto the tiles and let it harden.

You can see that it is important that the curve of the tool match that of the mirror, and also that the tiles are uniform in thickness. If you are using plaster, be sure it is sealed well. It would probably be a good idea to coat the face of the plaster with a thin layer of epoxy to help the tiles stick.

This is a very general discussion of making tools. Experiment with the materials and use your smarts to keep you out of trouble.

Working Place

My favorite method for working mirrors by hand is on top of a 55 gallon drum with 300 pounds of sandbags in it. You can buy drums at salvage yards, and sandbags can

be bought at nurseries.

One reasonable substitute for a barrel is a sturdy counter — remember, you don't have to walk around your glass. Another is so obvious it's usually overlooked: I used to grind and polish on my knees with the mirror on the floor. This proved successful, but the trouble is learning to walk again after ½ hour of polishing.

It is ideal to have two working areas — one for grinding and another one for fine grinding and polishing. For reasons of cleanliness and temperature uniformity, polishing is better done indoors. Grinding with abrasives larger than 30 microns is messy and, depending on your climate, may be better done outdoors.

Grinding the Back Flat

The first step in generating the optical surface is to grind both back and front flat. When I say "flat," I mean "regular" more than flat. The back can be a few thousandths of an inch convex or (preferably) concave, but it must be free from astigmatism, or what opticians call "cylinder." But flat is best. Even if the back has been Blanchard ground, you will still need to grind it smooth with 220.

Grinding the flats can be done with a glass or tile grinder. The best way to do it is to grind two blanks, one on the other. This way you get two flattened for the work of one.

The front, that is the side the curve is to be ground on, needs to be regular to a much lesser degree. However, if grossly high and low areas are present near the edge, by the time you grind in your curve, you're still likely to be missing contact near the edge, and it will cost you a lot of work to bring the surface down to meet them. Remember: On the face side, you're concerned with low areas near the edge that might be left unground after the curve is ground.

To grind, place the mirror face up on something soft like an old piece of deep shag carpet so the glass won't rock. (The carpet will be ruined.) Wet it down, add the appropriate amount of #60 abrasive, add a few pounds to the top of the tool if you wish, and grind like mad. When it stops making lots of noise, splash it off and start it again. After three or four wets, wash it off and look at the surface of the mirror. The high spots will be ground and the low spots will still look unground. This will give you some idea of what you're up against. Look at your tool as well and look how it started. Keep track of the convexity and concavity of both surfaces with a straightedge.

If your mirror starts going convex, concentrate grinding on the center with short strokes. If the convexity persists, grind with the mirror on top for a while. It's not a difficult thing to manage. John Dobson says, "Rough grinding is a caveman job; do it like a caveman. Eat well, sleep well, and work like hell."

A few isolated low spots on the back can be tolerated if they are small. What absolutely cannot be tolerated is a cylindrical curve on the back, or a curve in one axis and a flat in the other. This will cause the mirror to bend during grinding and polishing, and you will happily polish away until you discover that the mirror has astigmatism. When you're satisfied with the flatness of the back, fine grind it through 120 and 220. When grinding with the fine abrasives, low areas will have coarser pits on them and you'll have no trouble seeing them. If the back has been Blanchard ground, it should not take long to grind it flat with 220. Just a warning: Blanchard grinding may give a perfectly plane surface — but grind it for planeness anyway. You're better safe than sorry.

Preventing Astigmatism

Grinding the back flat is just the first step in preventing astigmatism. The next step is the proper mirror support. Fine grind and polish the mirror face up. A thin mirror bends over the edge of the tool if it's worked on top, so the problem reduces to supporting the mirror from its underside. The best way I know is to support it on a piece of deep shag carpet. The capet will support the mirror and will allow you to rotate the mirror with no trouble. The carpet goes between your mirror and your work surface which, by the way, must also be flat. (Plywood or particle board is flat enough.)

The key to the success of the technique is to rotate the mirror on the carpet frequently while working. This prevents non-uniformities in the support working into the mirror and showing up as astigmatism. Every time you complete one turn around the barrel, rotate the mirror about a third of a turn in the opposite direction. Randomly vary the amount of rotation you give it. If you're unfortunate and don't have a barrel, then rotate the mirror almost constantly in the direction opposite the direction you rotate the tool. As simple as it sounds, this method is quite effective.

For machine working, it's not so easy because the mirror usually can't be rotated with respect to its support. This is why you don't want to make mirrors to be worked on machines too thin. For 16″ to 18″ mirrors, 1.62″ thick is the thinnest I would recommend.

There are several ways to support the mirror on a grinding and polishing machine turntable, but first make sure the turntable itself is rigid. It must not bend. If your machine lacks a sturdy turntable, one way to make one is to cast it out of Kerr plaster 4″ to 5″ thick.

One way to support the mirror is to block the mirror right to the base with pitch. This is somewhat risky because the pitch can deform the mirror. A more manageable way is to pour pitch on the base ⅜″ thick. Groove it like a pitch lap with grooves about ½″ wide. Cover it with a single piece of paper, and set the mirror on the paper and tape it down. Be careful not to tape it too tight. Let the mirror sit on this lap for 24 hours. The back of the mirror should press the pitch to its exact shape. Each time you take the mirror off for testing, put it back in the same orientation and let it sit again for a few hours. You must not let the grooves in the lap under the mirror press together. When they start closing in, regroove them. Although this method is not without its troubles, it is widely used in the optical industry.

Another method is an 18-point flotation system. I've never used this method for support while working a mirror, but there are those who swear by it. The problem seems to be preventing the mirror from rocking under the lateral forces of grinding and polishing.

Rough Grinding

Once you have the back of the mirror ground flat through 220 and the face reasonably flat, you're ready to start roughing the curve into the mirror. I recommend #60 carborundum for rough grinding. By the way, as in all optical work, be sure that you always maintain a bevel on the edge of the mirror throughout grinding.

If your mirror is light enough to grind on top, grind much the same way you would a smaller mirror. Your goal is to grind the curve from the middle out, timing it so that you reach the desired focal length at about the time the curve reaches the edge of the disk.

Start grinding by concentrating the center of the mirror on the edge of the tool. Use a long "W" stroke, occasionally stroking the center of the mirror out to 2″ to

3" from the edge of the tool, progressing around the circumference of the tool rotating the mirror.

For mirrors ground face up, a small tool is desirable — 75% of the mirror diameter or smaller. Rough grind the curve by concentrating on the center.

As grinding progresses, you must monitor the focal length of your curve. If the Sun is available, splash water on the mirror and focus its image on a piece of cardboard and measure the distance to it.

Alternatively, you can keep track of the sagitta of the curve. Calculate the sagitta of your curve. Find something that can act as a gauge equal to the sagitta of your mirror (the classic gauge is a drill bit). Check the progress of rough grinding by slipping the gauge under a straightedge placed across your mirror.

Rough grinding usually produces a grossly hyperbolic curve. Toward the end of rough grinding, start using shorter strokes to produce a smoother, more spherical curve. Shorter strokes also move the curve toward the edge.

It is not difficult to manage grinding so that the curve meets the edge at about the same time it reaches the desired focal length with a reasonably spherical form.

Placing the mirror face up and grinding with a moderate "W" stroke will also move the curve toward the edge, and tends to produce a more spherical surface. Leaving the mirror grossly hyperbolic will make fine grinding difficult.

Fine Grinding

We've all heard stories about fine grinding taking hundreds of hours. If done correctly, however, fine grinding takes a fraction of this time, and in fact, is one of the more manageable jobs in making a large mirror. Depending on your circumstances, about 2 hours of continuous work at each grade is usually sufficient.

Fine grinding rather naturally divides into two stages: before #220 and after #220. Before 220, you're getting the radius and a smooth curve. After 220, you'll need to pay attention to preventing astigmatism. I also switch from my rough grinding area to my polishing area at 220.

The fine grinding compound you start with depends on the condition of your mirror and fit of your tool. If you rough ground your mirror with 60 grit, you should start fine grinding with 120 grit before going on to 220. If you have been fortunate enough to have the curve generated, you can start with 220 providing your tool has a reasonable fit to your curve. If you are working with a machine, you can use 30 micron grit.

Fine Abrasives

For abasives smaller than 120, I prefer aluminum oxide to carborundum because it has less tendency to cause large pits in the fine-ground surface. There are several sequences of fine abrasives you can take, but as long as you are careful to have completely ground away the last abrasive pits before going on, you'll be all-right.

More than anything else, your sequence depends on the quality of the abrasive you use. Most abrasives you buy have a few larger abrasive particles in them. For example, although #320 is mostly 320, there will be some grains closer to 220 size in it, plus some much smaller stuff. There is nothing wrong with this — but you must compensate for it by not taking a big step between abrasive sizes.

On the other hand, if you can get some really high quality abrasive like Microgrit®, (made by Micro Abrasive Corp., P.O. Box 517, Westfield, MA, 01086; phone 413-562-3641 for distributors.) you're in luck. 30 micron Microgrit® really is 30 micron. There are no 32 micron grains and no 28 micron grains — just 30. As a result, you can spread out the size you use. For example, I use #220 followed by 30 micron, 12 micron, and 3 micron.

When using more conventional abrasives, such as those available from Edmund, the sequence should be 220, 320, 400, 600, E305. There is not too much difference — but the 3 micron is finer than the E305.

It is difficult for me to even guess how much abrasive you'll need. I've never kept track of it. Depending how you happen to use it, the amount can be quite small or large. If you clean the glass after each wet and start by sprinkling new abrasive on the wet glass, you may use as little as a tablespoon of the finer fine abrasives for each grade. If you use the abrasive suspended in water and pour it on the glass, a cup of abrasive may not be enough. For 120 and 220 abrasives, the amount varies mostly with the amount of work you need to do. On the average, I've found 2 to 3 cups of 120 and 1 cup of 220 will do for me.

Getting a Sphere

Even the most careful finishing up job with 60 grit will leave the curve somewhat hyperbolic. After 60 grit, your main interest, besides removing the pits, is getting the mirror spherical. At this point, the support of the mirror is not at all critical, but using a piece of carpet under the mirror will allow you to rotate it easily.

Start by sprinkling the abrasive on the face of the wet mirror, as you did with smaller mirrors — not too much and not too little. Place the tool down edge first, and start grinding. Walk around the barrel, rotating the tool as you go, and also rotating the mirror every time around.

A solid tool traps abrasive in the center of the mirror and resists grinding the mirror spherical. When you first start a new and smaller abrasive, this shows up as a tendency to form a large bubble in the center, especially in the larger abrasives. Remedy this by using short "W" strokes and stirring the abrasive under the mirror every minute of so until the bubble is gone. To stir up the abrasive, just run the center of the tool clockwise around on the 50% zone of the mirror once or twice while you spin the tool clockwise. You will need to do this often all through fine grinding.

Because a segmented tool does not trap abrasive, a spherical curve will come a good deal more rapidly. A short "W" stroke serves well here, too.

When the wet comes to the end, stop grinding, separate the mirror and the tool, add more water and grit, then continue. If you have a tile tool, you can slop some water and grit on from the side without separating the mirror and tool, but don't drag the tool off on the edge of the mirror — this can roll off the edge. Instead, pull the tool three-fourths of the way off, then lift the tool up. In the finer abrasives this is difficult. A solid tool won't want to separate, and lifting will tend to pull the tiles off a tile tool — so take it easy.

As you probably suspected, you're done with 120 when the surface looks evenly ground and no 60 grit pits remain. Don't be fooled by some of the larger pits that 120 can make itself. These will come out in 220.

Going on to 220

As you begin 220, start to pay a little more attention to preventing astigmatism especially if the tool is thin. Be sure to rotate the mirror on a regular basis, and be sure you're grinding it on something soft. Also, keep mixing the abrasive between the mirror and the tool. In most respects, 220 is about the same as 120, except that this is

your last chance to remove any large pits and the surface must be spherical when you finish 220.

To control pits, follow the progress of the ground surface with a loupe magnifier. If you've had your curve generated, watch the generator marks closely. They can fade into the ground surface and seem to be hidden — and you will not know it until they're still there when you polish.

You should remember that 220 can leave some isolated pits a bit larger than the normal 220 pit size. However, you can tell these pits from leftover 120 pits because they will not stay in the same place after a spell of grinding. It is not uncommon for an ATM to grind extra hours trying to remove these pits when, in fact, they are caused by the abrasive and will be removed by the next abrasive. But don't ever let this be an excuse for failing to remove all the pits from the previous abrasive.

After a couple of hours of 220, you should be ready for the light test and 320 or 30 micron grit.

The light test is a very good test for the evenness of your ground surface. This test is described in detail in many telescope making books, and is very easy to apply. Place a light several feet behind your face-up mirror. Stand back from the mirror a couple of feet and lower your eye until the angle between the light, the mirror, and your eye is so large that the surface takes on a shine. The finer-ground the surface, the less extreme the angle.

Study the surface: it should stay evenly lit from edge to edge as you move from side to side. If the center of the mirror is hazy, it has not been fully ground by your latest abrasive. That also suggests that the mirror's curve is not spherical — so continue grinding until it is. This test will only give information on the overall smoothness of the ground surface, and is not a test for isolated pits.

Keeping the edge properly beveled becomes more important as fine grinding progresses. After finishing 220, I like to fine grind the bevel through 12 micron grit. This helps prevent scratches at the edge in the finer stages of fine grinding and polishing. To fine-grind the bevel, obtain a small piece of sheet metal or brass 2" to 3" square. Tape the sheet to a block of wood the same size, leaving the face of the sheet exposed. Start grinding the bevel with 220 grit, rounding it off. When the bevel is round with 220, you can continue to fine grind the same way through the finer abrasives, or wait and grind the bevel with smaller abrasives as you use them on the mirror.

Meanwhile, here is a good time to get a very accurate reading of your focal length. The 220 fine-ground and spherical surface, when wet, reflects an image of the Sun that can be accurately focused and measured.

The Fine Side of Fine Grinding

#320 and 30 micron aluminum oxide are about the same size, and they are your next abrasive. From now on, the precautions described in the "Preventing Astigmatism" section must be applied; cleanliness is also an important factor. Use the normal precautions, wash up thoroughly so you don't carry grit in your clothes, and keep your work area clean.

I prefer to suspend fine abrasives in water, although sprinkling very small amounts of abrasive on, then smearing it around with your wet hand is acceptable. For suspending abrasives, I use 1 tablespoon of abrasive to ½ cup of water. This goes a long way when using a solid tool. More abrasive mixture may be needed with a segmented tool.

In the finer stages, you should grind at a slow, steady pace being very careful not to let the surfaces get dry. If

they show a tendency to stick, or if it's hard to push the tool center over center, it's a sign the mirror surface is not spherical. Keep the abrasive stirred and use a shorter stroke for a while to remedy the situation.

If you're grinding with a solid tool, be careful not to let the tool and the mirror stick together. If they do get stuck tight, you must act quickly. Splash water on the exposed mirror, then place a 2x4 on the edge of the tool and hit it hard with another 2x4. Be careful the tool does not fly off and land on the floor. Do not use a hammer. I've seen it done: if you slip, you will break the mirror. If they refuse to separate, soak them in warm water.

Sticking is caused by a vacuum between the tool and the mirror. Segmented tools will not stick unless you leave the tool and the mirror together until the water dries off.

Continue to keep track of pits as before. Apply the light test often — it is effective from here on out, so use it. Continue as described through your finest abrasive. The smaller the abrasive gets, the more danger of getting a scratch from the tool. You must be increasingly careful. In these finer stages the light test can be done without a light, because room light will be sufficient. With your eye at the correct angle, you'll see an evenly illuminated mirror surface. A note of caution: With the finest abrasives, rubbing the mirror with your hand will give it an extra shine in that spot and will reflect more light in the light test.

Next: Polishing

When your final abrasive is complete, your mirror is ready to polish. Don't discard the grinding tool or put it to other uses: it may be required again if you find that you have astigmatism in the mirror after your first polishing period. Part two of this article will discuss pitch laps, polishing, figuring, testing, and most important for big mirrors, test interpretation.

I have enjoyed receiving letters from you about my articles in TM. As much as I regret it, however, I wasn't able to answer all of them. I can't help you get glass or find suppliers. For the supplier problem, TM is more informed than I am and they will continue to pass on whatever information they have through the magazine. Remember: When you go to the effort of finding out something that may be helpful to others, write it down and send it to TM.

Meanwhile, I'll do my best to answer technical questions that I might not have covered in the article. You don't need good luck, so I won't say it. All you need is a chance to learn for yourself how to make a large mirror.

Bob Kestner
1792 Montrose Drive
Concord, CA 94519

■

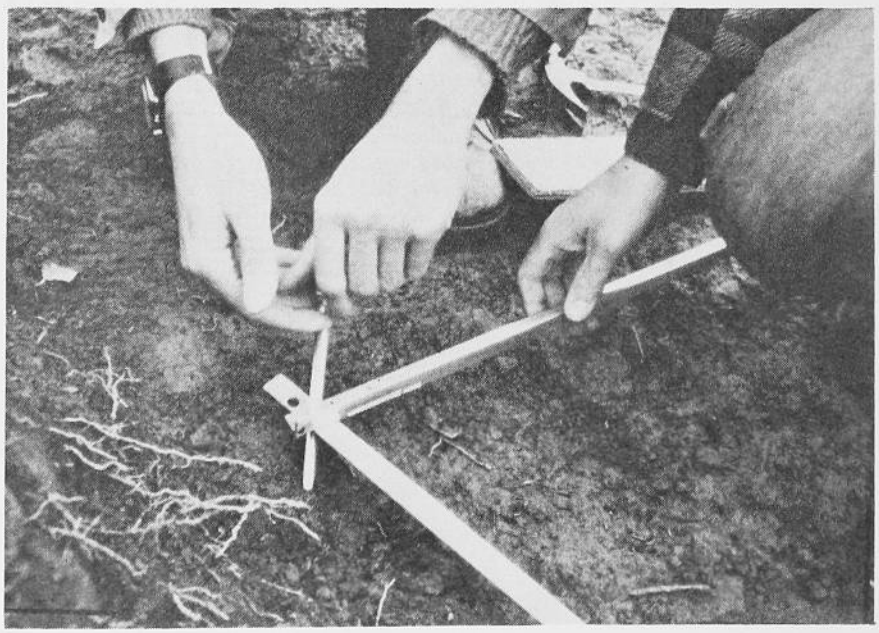
Constructing a Club Observatory

Individuals or clubs with a large telescope know the difficulties of moving the instrument outdoors for observing sessions. The time required to get a decent polar axis alignment, along with the difficulties in assembling and disassembling the various components can reduce even the most avid enthusiasm to nil after a few sessions. An enclosure for the observer and telescope is a must if serious observing programs are to be carried out year round.

However, most individuals don't have the means to construct their own building and most clubs don't have land available to them for such a project. The Albany Area Amateur Astronomers experienced these problems, too; but the club was able to overcome them in an 18-month program. Here's how we did it.

To begin, don't assume something that looks difficult is impossible. At first, acquiring a permanent observing site certainly seemed an impossible task. Nevertheless, the Albany group was given permission to use several acres of town property simply by asking! A nature preserve had been formed out of a large parcel of land that had been informally used as an observing site for a number of years. The president of our club presented our plan, including drawings of our proposed building, to the park planning board. They considered an astronomical observatory to be in keeping with the nature of the park and quickly approved our request.

Clubs considering such a project should remember that most town boards do not understand the nature of amateur observatories and therefore should be prepared to answer questions that may not seem reasonable. Concern for safety, insurance liability, and noise control are of upmost importance in the minds of town officials. A slide show outlining club activities and showing observatories constructed by other amateur groups may help convince board members of the value of the project.

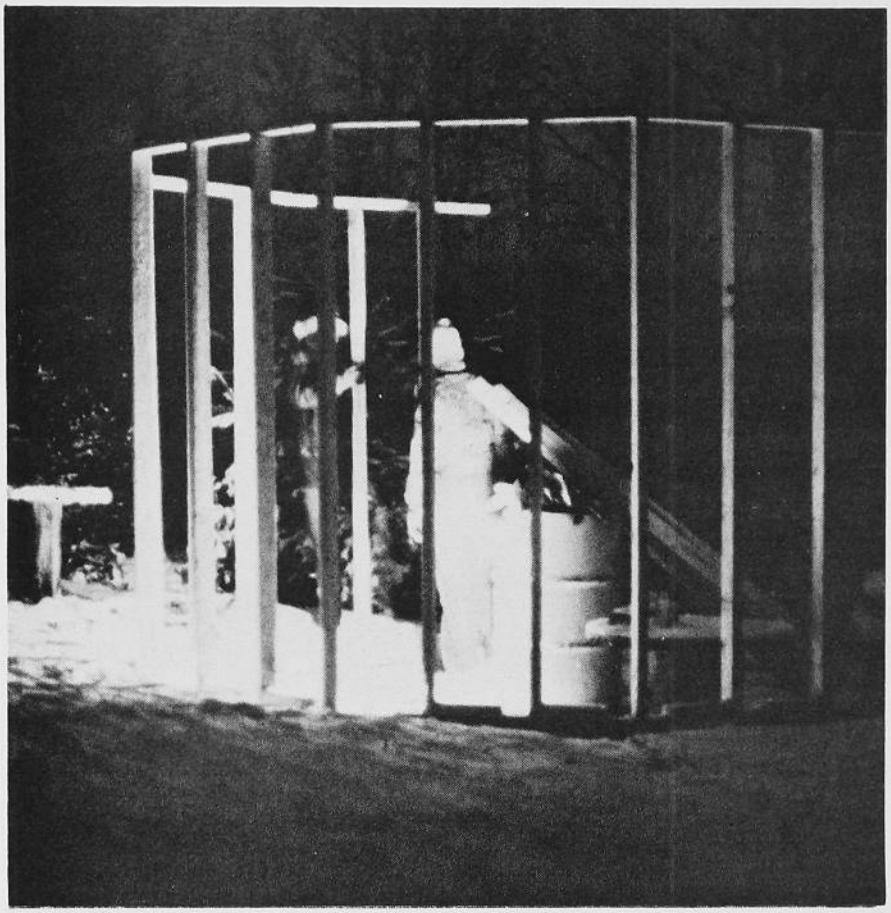


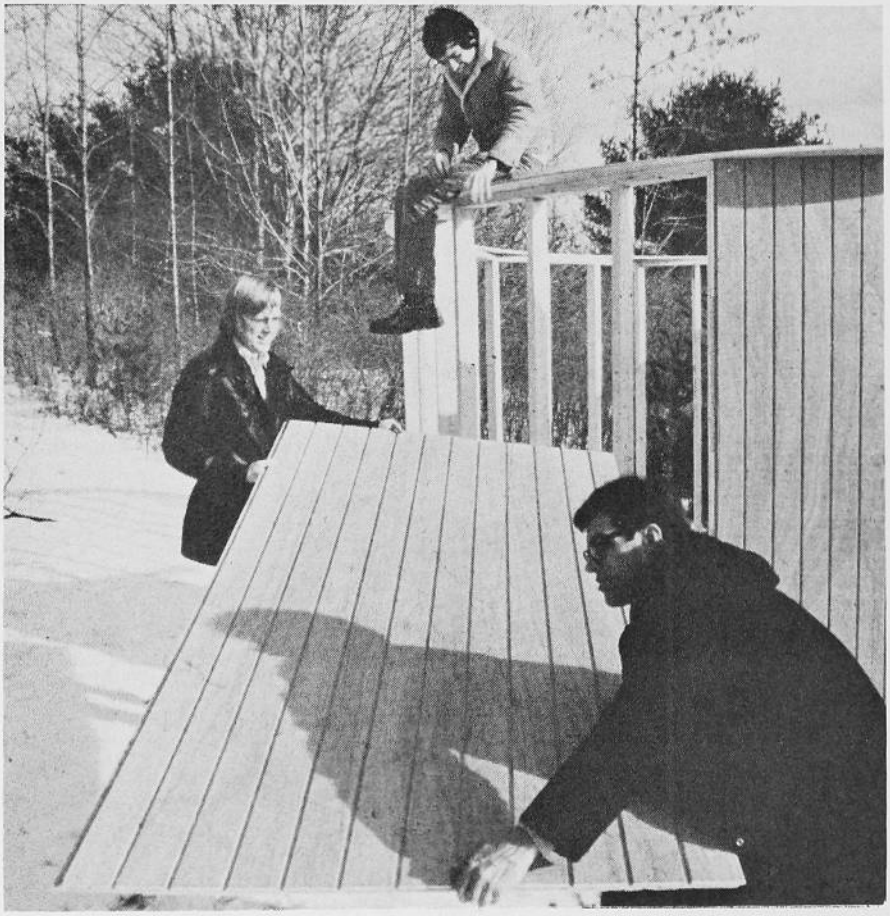
Fund raising is next, and for the actual building, it can be done in a variety of ways. Our club was immediately able to raise $400 in donations from its own membership. With the land and the telescope already secured, the author approached several area builders, starting with the best prospect. A simple request for materials accompanied by a good explanation of the value of the observatory to the public was sufficient to raise several hundred dollars worth of material.

The local supply companies were then contacted and told that one of their larger customers had given the project support. The suppliers, not wanting to be left out, felt obliged to follow suit. Finally, other suppliers not connected with the builder were told that several area vendors had given to the project. With a promise to be mentioned in any newspaper accounts of the observatory, the majority of the businesses donated materials. Of the dozen or so contacted, only two refused any help.

Bashful astronomy clubs should keep in mind that it is not the individual who is "begging" for help but rather it is a group project that will supply a public need in the community. Do not be afraid to be specific in your requests. If you require 10 sheets of plywood, then ask for 10 sheets of plywood: a prospective supporter is most likely to respond best to a specific request. Thank you notes, invitations to star parties for the owners and employees, and perhaps a plaque in the building thanking them again, will go a long way in encouraging continued support.

Constructing an observatory requires a different set of skills than fund raising.





While most members did not have much experience with building, it was our intention to do all of the work ourselves. Previous work done on a sliding roof building had provided us with some experience in working as a team. The older building also indicated that a domed observatory was required for year-round use as the winter cold and wind proved too much in an open roofed structure.

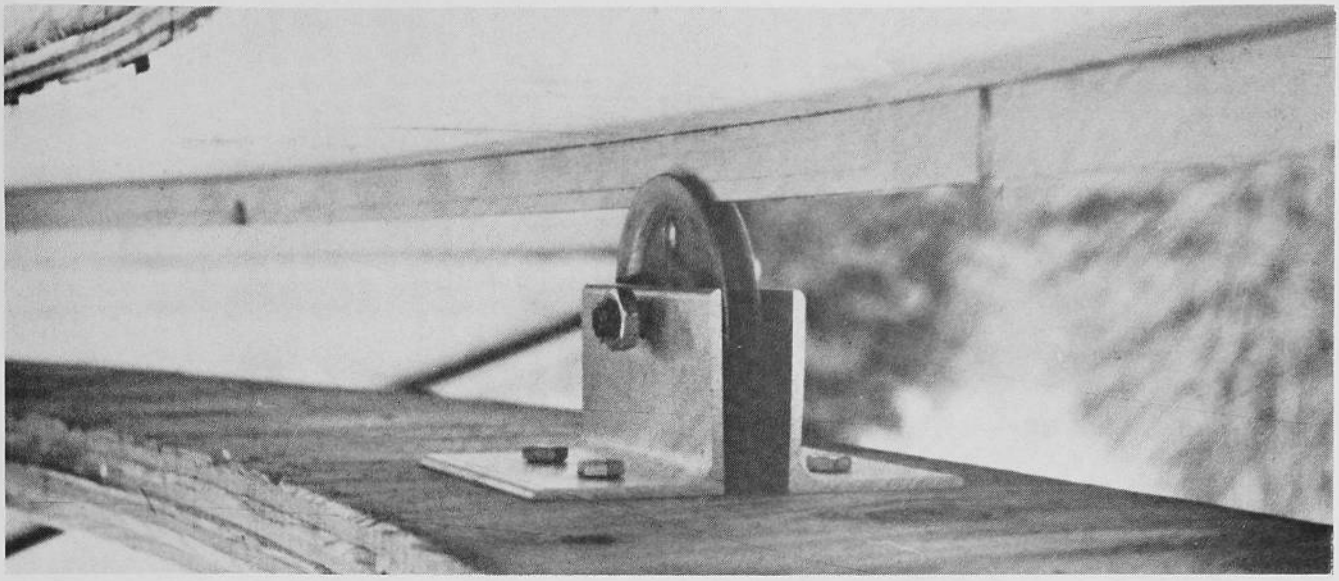
Our telescope, a 12″ Tinsley on loan from the Dudley Observatory, dictated the size of the building. The instrument, a Cassegrain, has a short eyepiece-to-declination-axis dimension. This means that the height of the eyepiece above the floor would not vary greatly as the telescope was moved from horizon to zenith positions. In addition, the eyepiece is higher than in many Newtonian telescopes. The eyepiece height allowed the use of a full size door.

In a building designed to be used by a large number of people in dark conditions, it is important to eliminate any safety hazards caused by unusual construction. After a great deal of discussion and planning, we decided that the building would have eight-foot walls with the observing floor raised 16″ above the footings. The eyepiece height would therefore require a small step up when looking near the horizon but be at a comfortable height when looking overhead.

The diameter of the structure was fixed at 13′ for several reasons. This size allowed for a 10-sided support structure for the dome with each wall having a width of a sheet of plywood (48″). It also allowed constructing the dome off site and trucking the finished dome to the observatory in halves. An outline of the building was formed with string on the actual site in order to be sure of sufficient size for several people.

A concrete post foundation was planned as this allowed for small batch mixing to be carried out over a period of several weekends. To accurately place the piers, two pieces of aluminum angle were used. One served as a radius bar and the other was drilled to provide the correct inter-pier spacing. Using a piece of threaded rod as a central pivot, the combination was used like a pair of dividers as we went around the circumference of the building.

A rod was placed in each pier location and the holes were dug and filled with concrete. The top of each hole was fitted with springy fiberglass rolled into a cylinder and allowed to snap tightly against the inside of the hole. This form was leveled using the radius bar and a builder's level. The combination divider was again used to place a threaded rod in the top of each pier which holds the sill to the foundation.

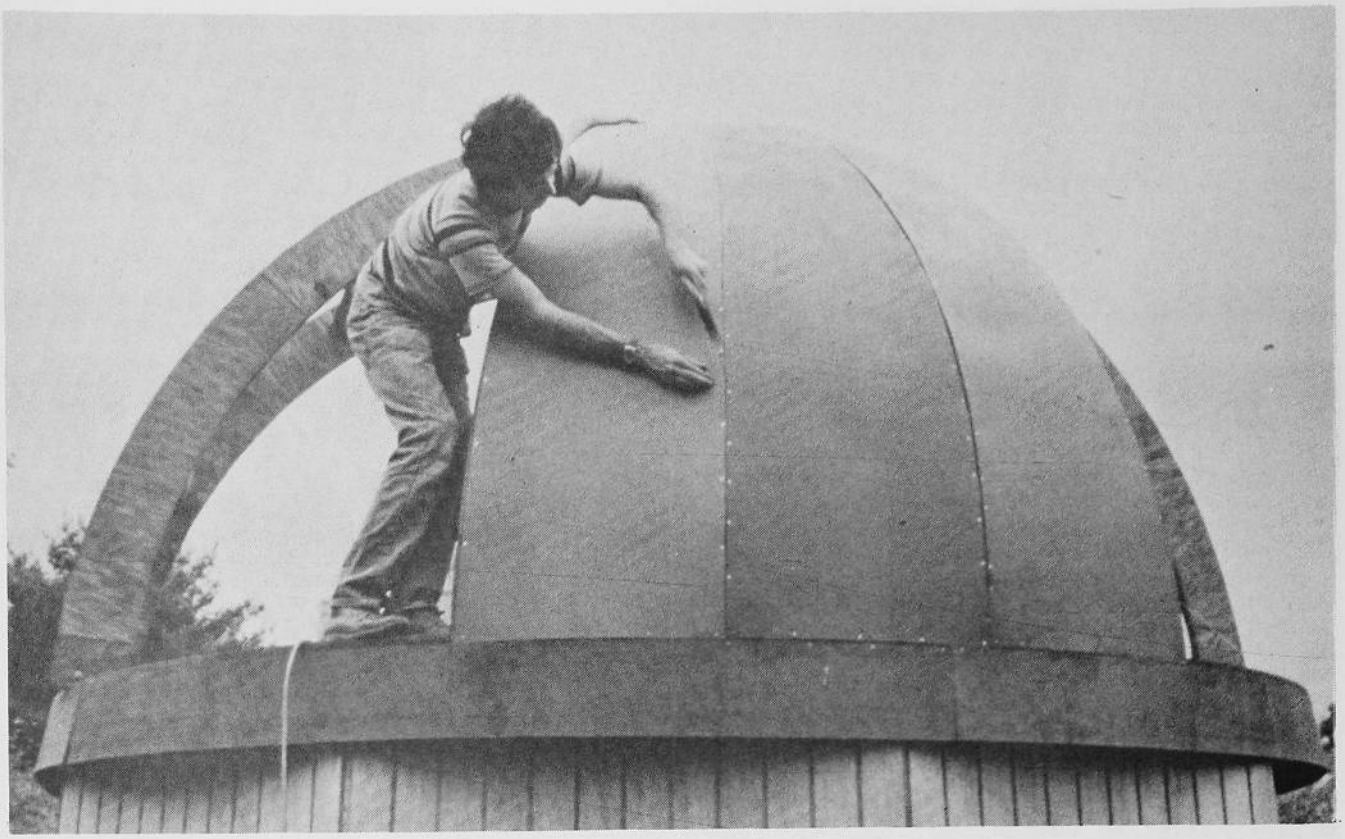


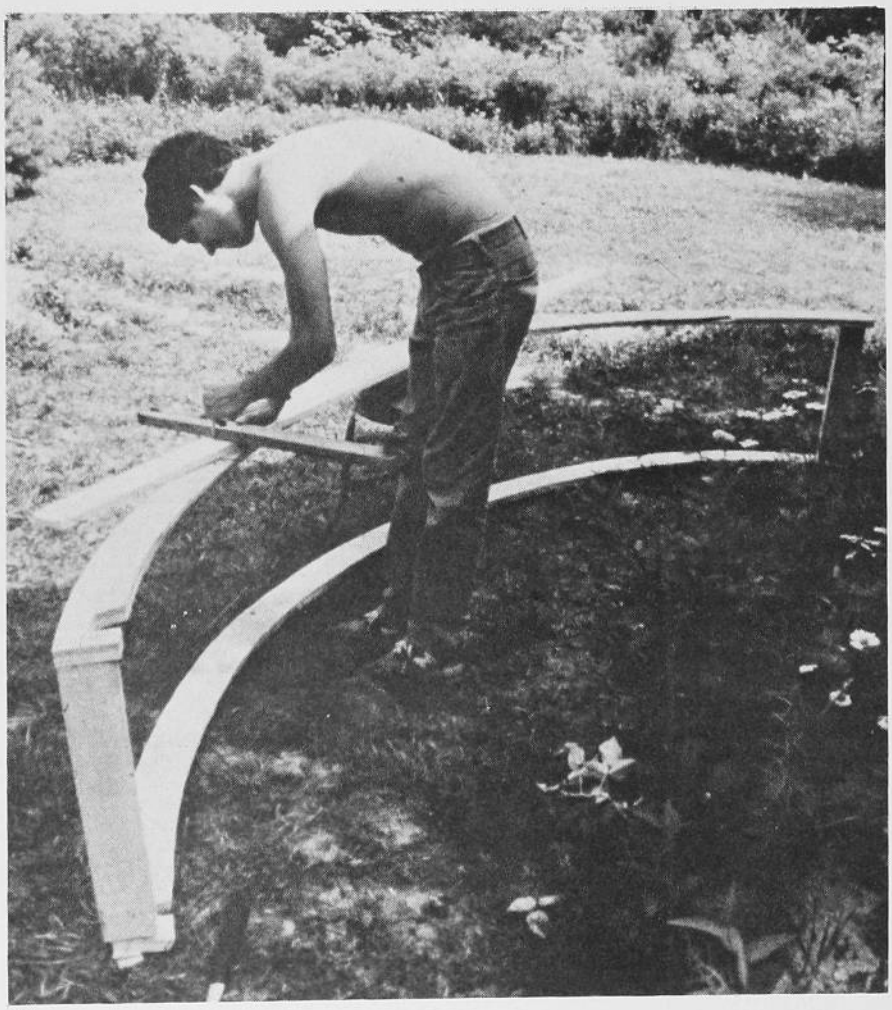
The telescope pier was formed from two 55-gallon oil drums, brazed together and inserted into a four foot deep hole. It was early December, and below zero weather was expected shortly after pouring the concrete, so we insulated the piers with bags of pine needles and used light bulbs as heaters to keep the concrete from freezing. While the cold was even more severe than we expected, the concrete cured without any problems.

The sill was constructed from two 2x6s spaced so as to allow a full-width 2x4 on top. Each four-foot length of sill was cut on a radial arm saw to an angle of 18°. Each sill was bolted to the foundation using a specially formed steel bracket that also connected one sill segment to the next.

A standard wall was constructed on top of the sill in a driving snow storm that threatened to trap us all at our observing site. Each four-foot wide wall shared a common stud at the juncture points. This stud was ripped length-wise to form a "V" with a 36° point. This allowed the plywood sheathing to be firmly attached at the corners. At the top of the wall, two layers of ½" plywood were attached to form a ring 9" wide. The ring served as a support for the aluminum track and also kept the building fairly circular. A line was drawn to indicate the position of the track, and the outside edge of the ring was then trimmed to make it a perfect circle. The aluminum track (which supports the wheels guiding the dome), was formed by cutting and bending a small aluminum angle. It was fastened to the base ring every 2" using flat-head wood screws. The finished rail is circular to within one sixteenth inch.

While the walls were being built, work was started on the dome. Forty arcs of ¾" plywood were cut on a band saw and laminated to form a ring 10" wide and 1.5"

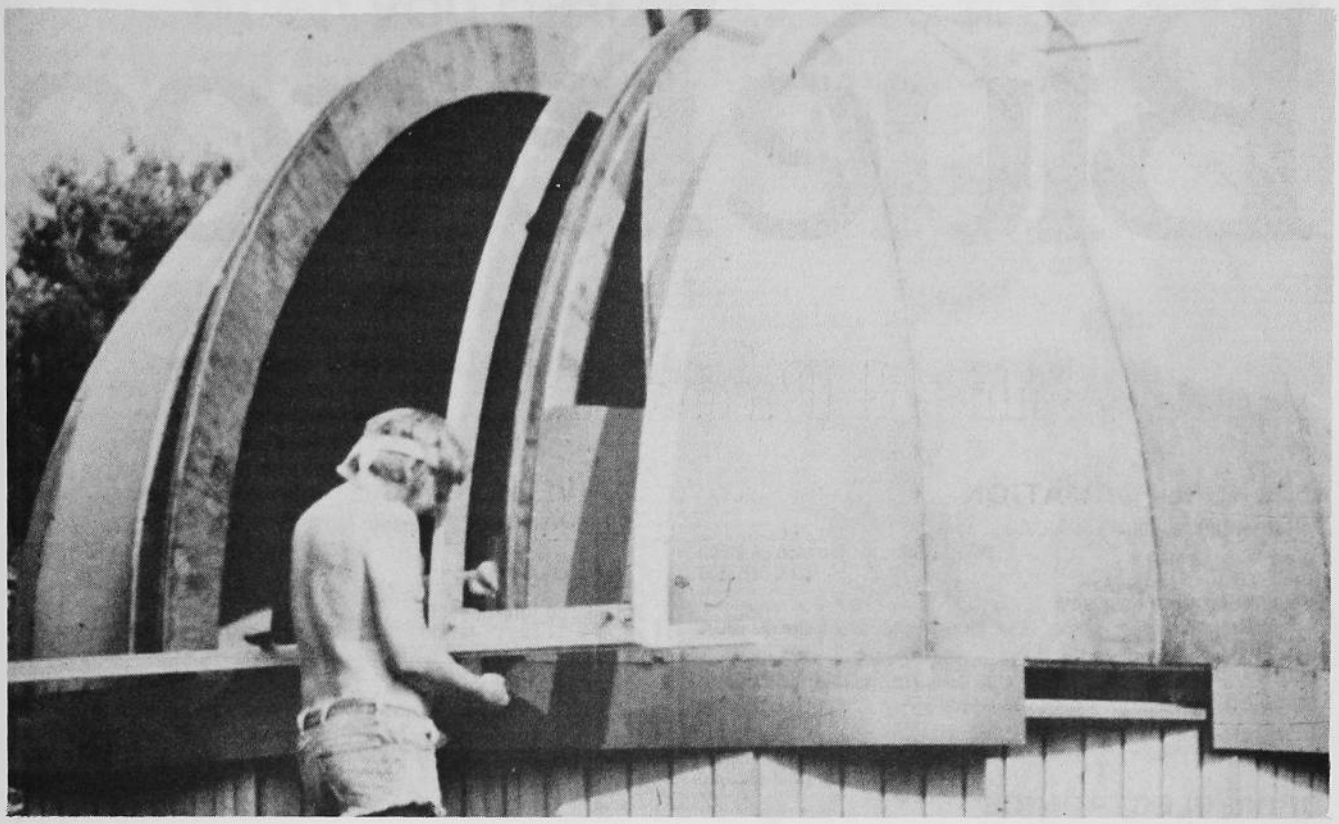




thick. One ring was made as the base of the dome and another was formed in two halves to serve as the slit opening. Two upright ribs were spaced 36″ apart and bolted to the base using aluminum angle. We now had an upper and lower terminus for the radially spaced minor ribs. The smaller ribs were made of two layers of ½″ plywood cut into arcs 4″ wide and fastened to the base using aluminum angle.

Except for the initial assembly of the main ribs, all work was done in place on top of the observatory walls. Each rib was cut to length by the "cut and try" method. Our dome is not quite symmetrical as we neglected to support the base ring properly in the early stages of construction. The resulting sag in the base ring is now part of the finished dome. However, it does not seem to affect the appearance or the operation of the dome. After several ribs were in place, gores of ⅛″ fully tempered masonite were fastened down using a hot melt adhesive and sheet-rock nails. The gores were cut from 2′ by 8′ sheets that had been held in place and marked. Each sheet was pulled over the ribs and the outline was traced using the ribs as a guide. Some trimming was still required as it is difficult to get a flat sheet to follow a compound curve. Twelve sheets of masonite were required for the dome, its base-ring skirt, and the shutters.

After coating the dome with polyurethane, two aluminum tracks were placed to carry the bi-parting



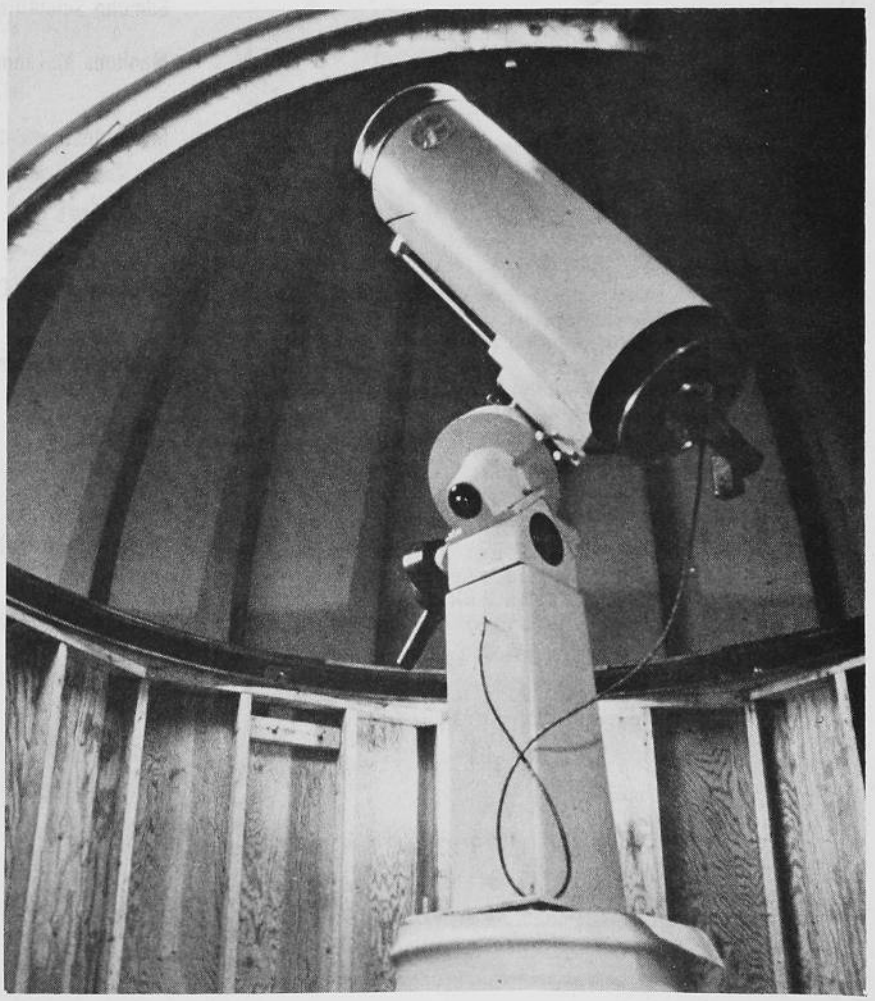
shutter slit cover. The doors were constructed of plywood ribs and masonite. It required 80 arcs of ½" plywood to complete the minor ribs. Obviously a band saw should be used if at all possible.

The shutter doors are yet to be fitted with a wire opening mechanism such as the one outlined in ATM Book II. The dome will also be pulled around using a wire that is supported by brackets fastened to the base ring. This wire will be given several wraps around a pulley attached to a reversible motor. The pulley should just clear the brackets as the wire pulls the dome around. (Anyone who has had experience with a driven wheel on a heavy dome will understand why we decided to use a wire instead.) The building has been fitted with a metal door that opens outward as just inside the door there is a single step up to the observing floor. The inside of the building is to be finished with a tile floor and wood paneled walls.

Our experience in constructing this observatory has been a very rewarding one which has helped our club grow in both membership and interest. A project such as this gives members the opportunity to trade skills and discuss problems outside the usual astronomy shop talk.

Mark Urbaetis
Rt. RD 2
Box 250
Rexford, NY 12148

■



Blue Pages

Classified Product Directory

BOOKS/INFORMATION

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9660

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

DRIVE ELECTRONICS

Abraxas Electronics ..... P.O. Box 1093, Littleton, CO 80160 (303) 979-6102

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

REFRACTOR KITS

Anyone who can grind and figure a mirror can make an objective lens. The remarkable image quality is ample reward for the effort.

We have assembled kits of first-quality materials to build a diffraction-limited air spaced achromatic objective of 3" or 4" aperture.

Kits include crown and flint lens blanks, glass tools, abrasives, polish, templates, specifications, and detailed instructions to advance the amateur through the art of lens making. Lens cells and tubing are available to complete your telescope.

We also carry mirror kits and optical supplies at competitive prices.

Catalog/price list available. Please send 25 cents to:

N. REMER OPTICS
Box 306T
Southampton, PA 18966
(215) 355-3086

DRIVE MOTORS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

EYEPIECES

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Dodd Co. ..... 7795 W. Ridgewood Dr., Parma, OH 44129 (216) 886-2828

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Manitoba Museum Shop ..... 190 Rupert Ave., Winnipeg, Manitoba, R3B ON2, CANADA (204) 956-2830

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

Unitron Instruments Inc. ..... 175 Express St., Plainview, NY 11803 (516) 822-4601

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

FILTERS

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

LENS KITS

N. Remer Optics ..... Box 306T, Southampton, PA 18966 (216) 355-3086

When you build your own scope, you want to use the best materials available.

UNITRON offers the ATM the finest quality components and accessories for refractors, reflectors and catadioptric instruments. Choose from a wide selection of:

A EYEPIECE HOLDERS

For 24.5mm

Star Diagonal	$15.00
2X Barlow	8.00
Erecting Diagonal	36.00
Erecting Prism	30.00

For 1¼"

Star Diagonal	23.00
2X Barlow	23.25
Erecting Diagonal	40.00
Erecting Prism	27.00

B VIEWFINDER MOUNTING BRACKETS

For 23.5mm finder, pair	$ 8.00
For 30mm finder, pair	10.00
For 40mm finder, pair	13.00
For 60mm finder, pair	20.00
For 100mm guide scope, pair	45.00

C EYEPIECES

1¼" O.D.

40mm Mono	$25.00
20mm Erfle	40.00
25mm Ortho	31.00
18mm Ortho	29.00
12.5mm Ortho	27.00
9mm Ortho	28.00
6mm Ortho	29.00
4mm Ortho	32.00

24.5mm O.D.

25mm Ramsden	$16.00
18mm Kellner	16.00
12.5mm Kellner	16.00
9mm Kellner	12.00
9mm Symm	19.00
7mm Symm	19.00
6mm Ortho	24.00
5mm Ortho	24.00
4mm Ortho	27.00

D CAMERA ADAPTERS

Standard Adapter	$18.00
Deluxe Adapter	35.00

E T-MOUNTS

Pentax-K (Bayonet)	$ 6.00
Pentax (Thread)	7.00
Petri	13.00
Mamiya	8.00
Nikon	13.00
Exacta/Topcon	13.00
Konica	13.00
Canon	13.00
Minolta	13.00
Olympus	16.00

F VIEWFINDERS

Complete with mounting brackets

6X-23.5mm	$ 35.00
8X-30mm	45.00
10X-40mm	60.00
12.5X-60mm	148.00
8X-30mm w/diagonal	63.00
10X-40mm w/diagonal	75.00

G MULTIPLE EYEPIECE HOLDERS

For 24.5mm

Unihex rotary eyepiece holder	$56.00
Deutron double eyepiece holder	49.00

For 1¼"

Unihex rotary eyepiece holder	$56.00
Deutron double eyepiece holder	83.00

H MOUNTED OBJECTIVE

60mm f/8.3	$ 61.00
60mm, f/11.7	61.00
60mm, f/15	61.00
75mm, f/16	124.00
100mm, f/15	235.00

I OBJECTIVE OUTER CELL WITH DEWCAP

For 60mm Objective	$16.00
For 75mm Objective	24.00
For 100mm Objective	45.00

J PHOTOGRAPHIC GUIDE SCOPES

Complete with mounting brackets.

60mm, f/11.7	$152.00
75mm, f/15	285.00
100mm, f/15	548.00

K ASTRO CAMERAS

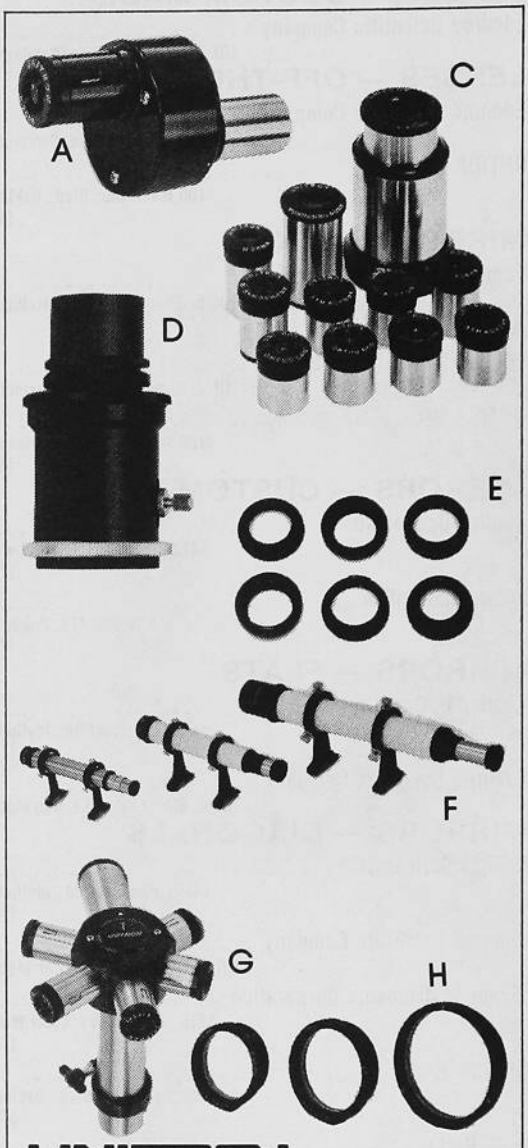
Model 220A, for Unitrons	$305.00
Model 220B, for 1¼" holders	305.00
80mm, f/5 Astrograph	715.00

L RACK & PINION FOCUSING MECHANISMS

Can be adapted to suit individual requirements.

Standard Model for 2.4" Refractors	$ 38.00
Standard Model for 3" Refractors	38.00
Deluxe Model	48.00
Super Model	100.00
Super Model with Focusing Scale	100.00
Coupling Collar for Deluxe Model, to fit 3 1/16" i.d. tubing	11.00
Coupling Collar for Super Model, to fit 4⅜" o.d. tubing	19.00

Prices, F.O.B. destination Continental U.S.A., subject to change without prior notice.



UNITRON
EXCELLENCE BY DESIGN

Send me more information about:

☐ _____

☐ Accessories catalog

UNITRON INSTRUMENTS, INC.
175 Express Street, Plainview, NY 11803, U.S.A.

TM.

master charge VISA

Name _____

Address _____

City _____

State _____ Zip _____

LENS BLANKS

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

LENSES — CUSTOM MADE

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

LENSES — OFF-THE-SHELF

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c
4100 MacArthur Blvd., Oakland, CA 94619
(415) 530-1234

MIRROR BLANKS

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

MIRROR KITS

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c
4100 MacArthur Blvd., Oakland, CA 94619
(415) 530-1234

MIRRORS — CUSTOM MADE

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Enterprise Optics
P.O. Box 413, Placentia, CA 92670
(714) 524-7520

MIRRORS — FLATS

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

MIRRORS — DIAGONALS

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

OPTICA b/c
4100 MacArthur Blvd., Oakland, CA 94619
(415) 530-1234

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

MIRRORS — OFF-THE-SHELF

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Enterprise Optics
P.O. Box 413, Placentia, CA 92670
(714) 524-7520

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

MOUNTINGS — COMPLETE

Celestron International
2835 Columbia St., Torrance, CA 90503
(213) 328-9560

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

Unitron Instruments Inc.
175 Express St., Plainview, NY 11803
(516) 822-4601

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

MOUNTINGS — PARTS

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

OPTICAL ABRASIVES — BULK

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c
4100 MacArthur Blvd., Oakland, CA 94619
(415) 530-1234

OPTICAL TEST EQUIPMENT

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

PREFORMED TOOLS, LAPS

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

SETTING CIRCLES

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

Free!
SURPLUS
CATALOG

We have gadgets galore . . . industrial and military surplus items that all you telescope makers, gadgeteers, and do-it-yourselfers just can't afford to overlook. If you have the knack for turning a thing-a-ma-jig into a golden opportunity, then our gadget gazette is just what you're looking for. Have an idea that needs some unusual lenses, eyepieces, timers, motors or perhaps gears? How about mirrors, finderscopes, tubing, glass filters or some other such thing? We have the gadget you're looking for. Just send for our latest FREE catalog.

JERRYCO

Write To :

JERRYCO
5700 Northwest Highway
Chicago, Illinois 60646

TELESCOPE ACCESSORIES

American Science Center
5700 Northwest Highway, Chicago, IL 60646
(312) 763-0313

Celestron International
2835 Columbia St., Torrance, CA 90503
(213) 328-9560

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Manitoba Museum Shop
190 Rupert Ave., Winnipeg, Manitoba, R3B 0N2, CANADA
(204) 956-2830

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

Orion Telescope Center
P.O. Box 1158-T, Santa Cruz, CA 95061
(408) 476-8715

Unitron Instruments Inc.
175 Express St., Plainview, NY 11803
(516) 822-4601

TELESCOPE PARTS

Dodd Co.
7795 W. Ridgewood Dr., Parma, OH 44129
(216) 886-2828

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Enterprise Optics
P.O. Box 413, Placentia, CA 92670
(714) 524-7520

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

OPTICA b/c
4100 MacArthur Blvd., Oakland, CA 94619
(415) 530-1234

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

Unitron Instruments Inc.
175 Express St., Plainview, NY 11803
(516) 822-4601

TELESCOPE TUBES

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

W.R. Parks
P.O. Box 6683, Torrance, CA 90504
(213) 532-6066

TELESCOPES, COMPLETE

Celestron International
2835 Columbia St., Torrance, CA 90503
(213) 328-9560

Coulter Optical Co.
54121 Pinecrest Rd., Idyllwild, CA 92349
(714) 659-2991

Dodd Co.
7795 W. Ridgewood Dr., Parma, OH 44129
(216) 886-2828

Edmund Scientific Company
101 E. Gloucester Pike, Barrington, NJ 08007

Enterprise Optics
P.O. Box 413, Placentia, CA 92670
(714) 524-7520

Manitoba Museum Shop
190 Rupert Ave., Winnipeg, Manitoba, R3B 0N2, CANADA
(204) 956-2830

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, CA 92626
(714) 556-2291

Hand Figured Telescope Mirrors

Null Tested
Aluminized and Overcoated
Sizes: 4¼" to 16"

10" F-6 Mirror $200.00
12½" F-6 Mirror $325.00

Also Available:

Mirror Kits • Refiguring
Telescope Parts & Accessories
Custom Made Telescopes

FREE
Complete Product Price List
On Request

ENTERPRISE OPTICS
P.O. Box 413
Placentia, CA 92670
(714) 524-7520

TELESCOPE MAKERS' HARDWARE

1. DOBSONIAN BEARING KIT. Consists of six 3" dia, 1/16" thick Teflon discs (3 spare), 4 smaller "tabs" of Teflon for elevation bearings, and a 14" dia hard polished aluminum ring. The ring is taken from a computer disc mass storage unit, and is much smoother than Formica, which makes the Teflon last longer. Instructions.

Complete Kit.....$12 Ppd
Teflon only.....$9 Ppd

2. OPTICAL ALIGNMENT WASHERS. Made of stainless steel. A 1/4" bore, half spherical washer tilts in the cone-shaped depression machined into its mating washer. Use them in collimation devices and as pivots for floatation cells. Instructions.

6 Pair, $3. Each additional 3Pr, $1

Please remit by cashier's check or money order to:
RICHARD D. SHAFFER
228 E. Pentagon
Altadena, CA 91001

CA residents please add 6% Sales Tax.

Letters

◄3

Brock-White Co. in New Berlin) did work out, so here's what worked for me.

First I mounted two 150-watt spotlights side by side on a board and turned the tube slowly under the lamps at a distance of about 1 to 2 inches. The wax melted readily, and I was able to wipe part of it away with paper towels. The remainder seemed to be absorbed by the tube. I then wiped the tube with the solvent "Carbo-Chlor."

I used one coat of premium "KILZ" purchased from Roobe Paint Company and two coats of heavy duty Alkyd Gloss Enamel.

The surface dried to a nice hard finish. Thanks for your help.

David Harrison
1475 Spring Drive
Brookfield, WI 53005

— And thanks for telling us what worked for you.

Non-Rust Hardware

Sir / I am writing to you concerning a supply source of brass machine screws. Such items as #2-56 Brass Filister machine screws can be purchased in small quantities from the Elwick Supply Company. This firm also stocks other brass hardware, stainless steel screws and bolts, and miscellaneous tools. The address for a free mail order catalog is:

Elwick Supply Company
Dept. 418
230 Woods Lane
Somerdale, NJ 08083

Because brass hardware is becoming extremely expensive, stainless steel fasteners may be a more economical substitute. An excellent source of stainless steel hardware is:

Fastening Products Co., Inc.
P.O. Box 151
Cheltenham, PA 19012

Please include an SASE with two first-class postage stamps for their price list.

I would also like some help in locating a source of either 20-gauge chromel or nichrome resistance wire for a dew cap that I am constructing. Do any of your readers know of a mail order source of this wire?

Marcus A. Maito
P.O. Box 177
Delavo, CA 93216

Little Fasteners

Sir / In regards to Earle Dodds' letter in TM #11 about finding small brass screws, may I suggest the following for your readers.

1. Nat Cam
   1835 W. Union Ave.
   Unit 15
   Englewood, CO 80110

Send for their catalog. They sell screws from 1-72 to 00-80 in filisters, round, flat, and hex head, plus lots of other good tools.

2. Campbell Tools
   2100 Selma Road
   Springfield, OH 45505

As above, screws are available from 2-56 to 0000-160, plus washers. Campbells has several catalogs; ask for their tool catalog and include $1.

3. Jensen Tools
   1230 S. Priest Drive
   Tempe, AZ 85281

I believe this company has screws also. Ask for their full catalog as their supplements may not list them.

I have dealt with all of these companies and have had no problems.

David I. Chrestenson
329 Seminary Avenue
Aurora, IL 60505

Two-Pier Weanling

Sir / Having been weaned on Warner & Swasey two-pier mounts, I was very happy to see your article in TM #11. Am I partial to McDonald Observatory's scopes? Lots of piers!

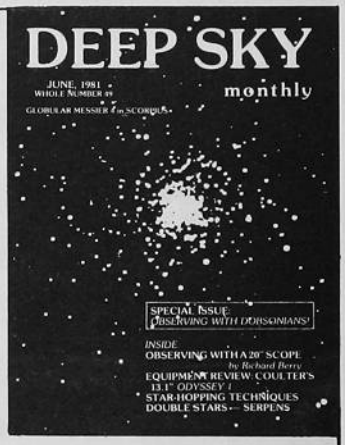
Also, I was pleased to see the Stellafane shots from the past, including the escaped convict shown on page 5!

John Gregory
Route A, Box 56F
Dripping Springs, TX 78620

DEEP SKY monthly, inc.
104 Oakhill Drive, Oxford, Ohio 45056 USA
Telephone (513) 523-5554

DEEP SKY ASTRONOMERS:

Get more out of your observing and photography!



DEEP SKY MONTHLY is the essential magazine for the amateur deep-sky observer and photographer — it's the place you'll find clusters, nebulae, and galaxies reviewed in-depth month after month to improve the quality of your backyard research. *DSM*'s feature articles cover all aspects of deep-sky astronomy — objects, equipment, techniques, and activities. Recent papers include such titles as "*Observing With A 20" Telescope*" by Richard Berry, "*Gas Hypersensitization Of 35mm Film*" by Dr. Jack B. Marling, and "*Observing Details In Galaxies*" by David J. Eicher. Regular monthly departments cover double stars, variable stars, clusters, nebulae, and galaxies — all matter beyond our solar system! Whatever deep-sky observing interests, you'll be pleased with *DSM*!

DSM is printed on heavy glossy stock, and is produced by a group of amateurs organized as a public, non-profit corporation, with the intention of serving fellow amateurs. Start your subscription today; please allow four to six weeks for delivery of first issue. Best wishes for future observing and photography.

Subscription rates:
$9/yr. in USA ($18/2 yr.)
$12/yr. elsewhere ($24/2 yr.)
Postpaid sample issue: $1
Submit all funds in US currency.